

(NASA-CR-143145) ANALYSIS AND COMPIRATION
OF MISSILE AERODYNAMIC DATA Interim Report
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INTERIM REPORT

on

ANALYSIS AND COMPIRATION OF MISSILE
AERODYNAMIC DATA

Conducted at

AUBURN UNIVERSITY

by

Faculty and Students
of
Aerospace Engineering Department

Under Contract NASA NSG 1002

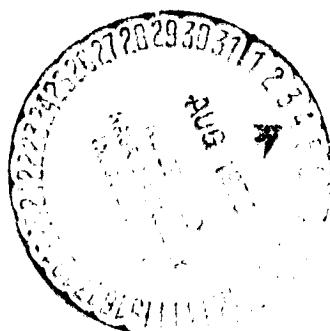
with

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Langley Research Center, Hampton, Virginia

Submitted by

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31 December 1974

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ABSTRACT

This summary document was prepared in order to facilitate dissemination of a large amount of missile aerodynamic data which has recently been declassified. Only summary data are presented in this report, but a list of reference documents provides sources of detailed data.

Most of the configurations considered are suitable for highly maneuverable air-to-air or surface-to-air missiles; however, a few cruise missile and projectile configurations are also presented.

The Mach number range of the data is generally from about 1.5 to 4.63; however, data for some configurations extend to subsonic Mach numbers.

The following longitudinal aerodynamic characteristics at various Mach numbers are presented:

- a) pitch control effectiveness, $C_{m\alpha}$
- b) drag coefficient at zero lift, $C_{D,0}$
- c) lift-curve slope at $\alpha=0^\circ$, $C_{L\alpha}$
- d) aerodynamic-center location, x_{ac}/l .

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SYMBOLS

A	body maximum cross-sectional area, $\pi d^2/4$
$C_{D,0}$	drag coefficient at zero lift, $\frac{\text{Drag at zero lift}}{q A}$
$C_{L\alpha}$	lift-curve slope at $\alpha=0^\circ$, per deg.
$C_{m\alpha}$	slope of pitching-moment curve at $\alpha=0^\circ$, per deg.
$C_{m\delta}$	pitch control effectiveness at $\alpha=0^\circ$, per deg.
$C_{N\alpha}$	normal-force-curve slope at $\alpha=0^\circ$, per deg.
$C_{N\delta}$	normal-force coefficient due to control deflection at $\alpha=0^\circ$, per deg.
d	maximum body diameter
l	body length
M	free-stream Mach number
q	free-stream dynamic pressure
x_{ac}/l	aerodynamic-center of lift location referenced to body length, positive aft
α	angle of attack, deg.
δ	angle of control deflection, positive trailing edge down, deg.
ϕ	angle of roll, deg.

Subscripts:

c	canard
f	fin
w	wing

Subscripts are used when there may be some confusion about which control surface is being deflected.

INTRODUCTION

Recently a number of documents containing missile aerodynamic data have been classified. In order to facilitate dissemination of the data contained in these documents, this summary document was prepared. It was not intended that all of the original data be included in this report, only summary plots of curve slopes and data suitable for comparison of the relative merits of the various configurations considered. A list of the reference documents is included to provide a source of more detailed data for configurations of interest.

Most of the configurations considered are suitable for highly maneuverable air-to-air or surface-to-air missiles; however, a few cruise missile and projectile configurations are also presented.

Twenty-nine documents have been summarized. Some of these were themselves compilations of data previously reported in other documents. Some of the documents summarized were never classified but are included to give a more complete coverage of the configurations that have been tested.

The Mach number range of the data is generally from about 1.5 to 4.63; however, data for some configurations extend to subsonic Mach numbers.

APPARATUS AND TESTS

The data summarized in this report were obtained originally in the Langley 8-foot transonic pressure tunnel and the Langley Unitary Plan wind tunnel. These tunnels are variable - pressure continuous - flow facilities. The 8-foot tunnel has a slotted test section which is about 2.44 meters square and has a Mach number range from about 0.20 to 1.30.

The Unitary Plan wind tunnel has two test sections, each about 1.22 meters square and about 2.13 meters long. The nozzle leading to each test section is of the asymmetric sliding block type which permits a continuous variation in Mach number from about 1.47 to 2.86 in the low Mach number test section and from 2.3 to 4.7 in the high Mach number test section.

The Reynolds numbers at which the tests were conducted varied from about 6.56×10^6 per meter to 9.84×10^6 per meter. Boundary-layer transition strips were used on the models.

Aerodynamic forces and moments were measured by means of a six-component electrical strain-gage balance located within the model and, in turn, rigidly fastened to a sting-support system. Angles of attack were corrected for sting and balance deflection due to aerodynamic loads and for tunnel airflow misalignment. The results have been adjusted to correspond to free-stream static pressure acting over the model base.

Since cruciform configurations may fly with wings in the vertical and horizontal planes or with wings in 45° planes, data at both $\phi = 0^\circ$ and $\phi = 45^\circ$ are presented for many of these configurations. The longitudinal aerodynamic characteristics were similar in both attitudes except for increased pitch control effectiveness at $\phi = 45^\circ$ due to deflection of four surfaces instead of two.

METHOD OF DATA PRESENTATION

The following longitudinal aerodynamic characteristics at various Mach numbers are presented in this report:

- a) pitch control effectiveness, $C_{M\delta}$
- b) drag coefficient at zero lift, $C_{D,0}$
- c) lift-curve slope at $\alpha = 0^\circ$, $C_{L\alpha}$
- d) aerodynamic-center location, x_{ac}/l

Maximum body cross-sectional area and maximum body diameter are used as reference area and length, respectively, for the aerodynamic coefficients. In one case (TM X-1538) where the body was not a body of revolution, the maximum frontal area and an equivalent maximum body diameter are used. It was necessary to convert the data in some of the reports summarized because different reference areas and lengths were used.

Conversion from body-axis reference system to stability-axis system was also necessary in many cases. In one case (TM X-846) there was insufficient data to convert to the stability-axis system. In that one case, the data is presented relative to the body-axis system. The moment reference center is shown on each model drawing included in the Data Summary. Drawings of model configurations were generally duplicated by xerox copy directly from the original reports; thus, not all model dimensions are given in the International System of Units (SI). In some cases where new drawings were necessary, model dimensions were converted to the SI system.

The aerodynamic center location, x_{ac}/l , is referenced to body length and measured positive aft from the nose. It was calculated with the following equation

$$x_{ac}/l = - (c_{m_a}/c_{L_a})(d/l) + (x_{mc}/l)$$

where x_{mc} is the distance from the nose to the moment center, d is maximum body diameter, and l is body length.

The data are shown in the Data Summary plotted against Mach number except in the cases where data for only one or two Mach numbers were available. In those cases the data are presented in tabular form. Each data summary contains a reference to the original report from which the data was taken. A complete list of the reports summarized is given in the last section of this report.

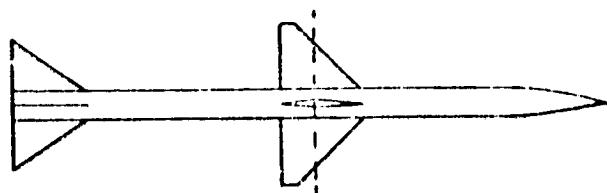
A summary of typical configurations considered is given in the next section. Not all the configurations covered in the Data Summary are shown, only typical examples. These examples were chosen on the basis of various configuration classification such as:

- a) wing planform shape.
- b) wing arrangement - cruciform or monoplane..
- c) control surfaces - wing, tail, or canard.
- d) surface arrangement - in-line or interdigitated.

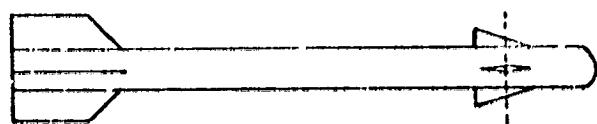
These configurations are grouped according to the missions for which they were originally designed. The arrangement of the Data Summary follows the same plan as the Summary of Configurations including, however, all of the configurations considered.

SUMMARY OF CONFIGURATIONS

AIR-TO-AIR

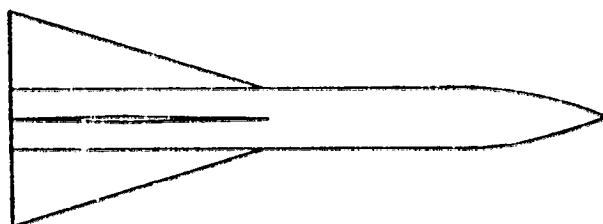


TM X-846

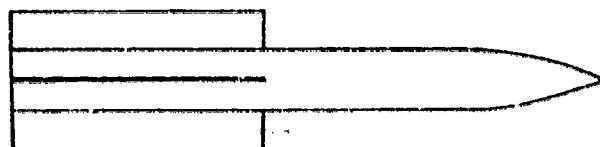


TM X-3070

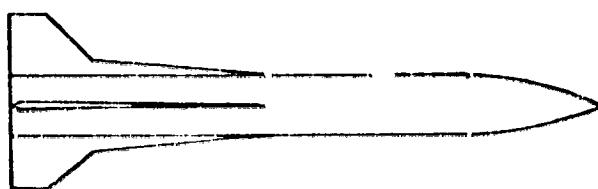
SURFACE-TO-AIR OR AIR-TO-AIR



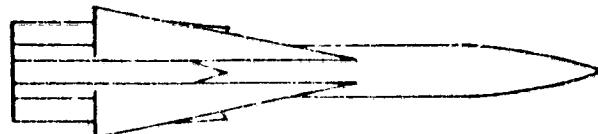
TM X-1839, TM X-2289



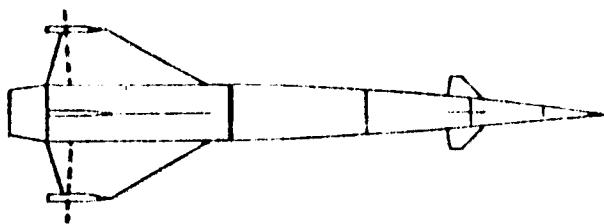
TM X-1839



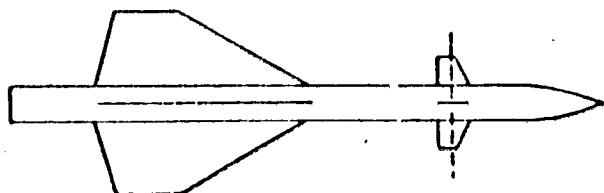
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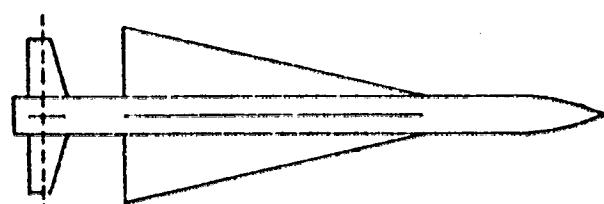
TM X-2491



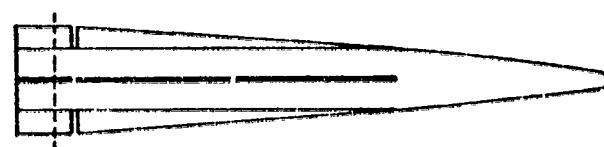
TM X-1309, TM X-1352, TM X-2367



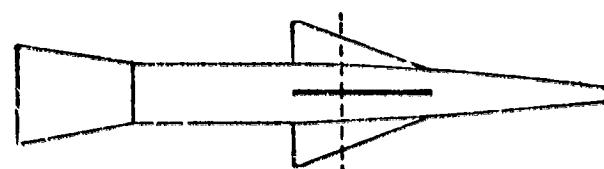
TM X-2780, TM X-1834



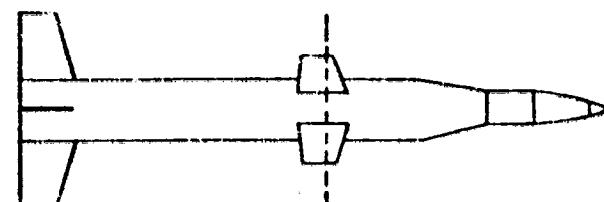
TM X-1834, TM X-2780



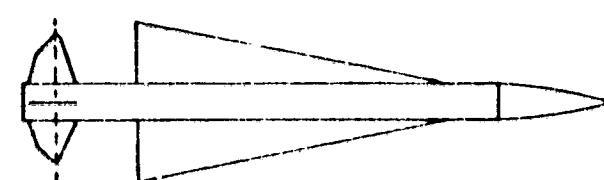
TM X-187



TM X-187



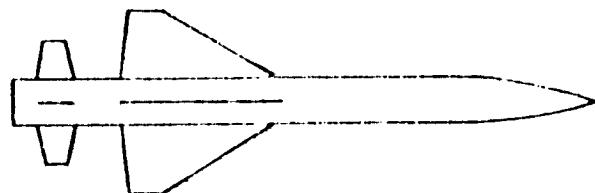
TM X-1184, TM X-1332



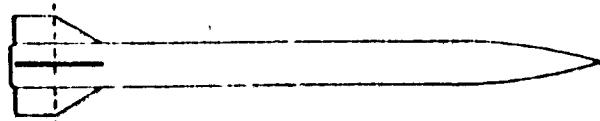
TM X-71984

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SURFACE-TO-AIR

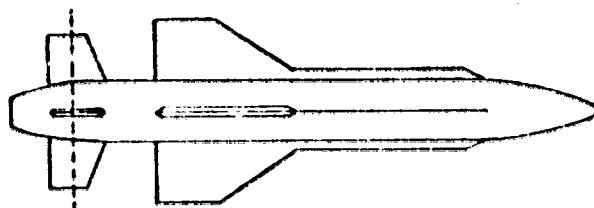


TM X-1025, TM X-1416, TM X-1751

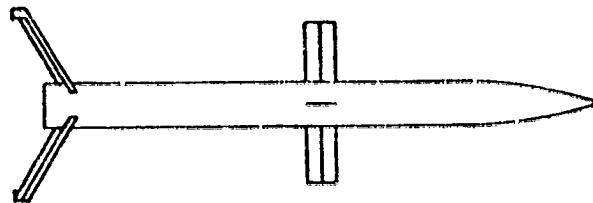


TM X-2774

AIR-TO-SURFACE



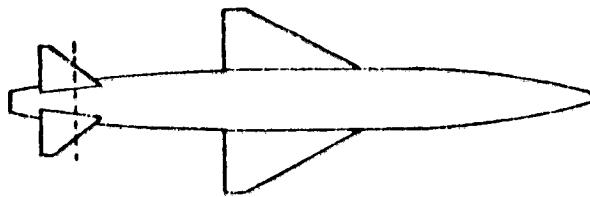
TM X-1112



TM X-1491



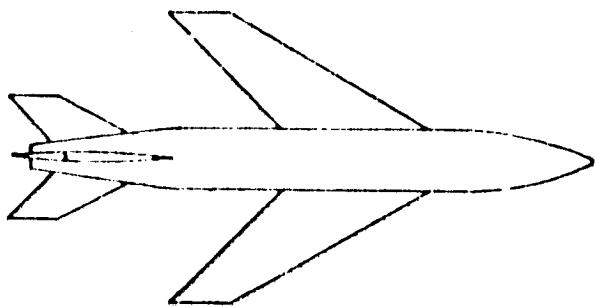
TM X-1492



TM L58C19

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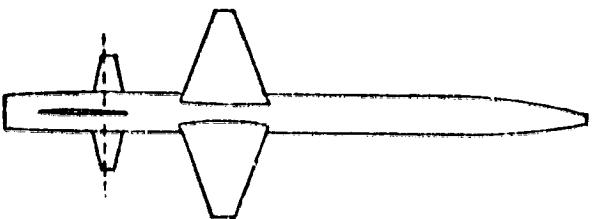
CRUISE, TARGET DRONE



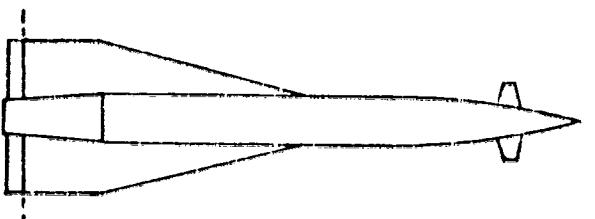
TN D-7069



TM X-1304



TM X-1538



TM SX-1531, TM SX-1961, TM SX-2299

PROJECTILE



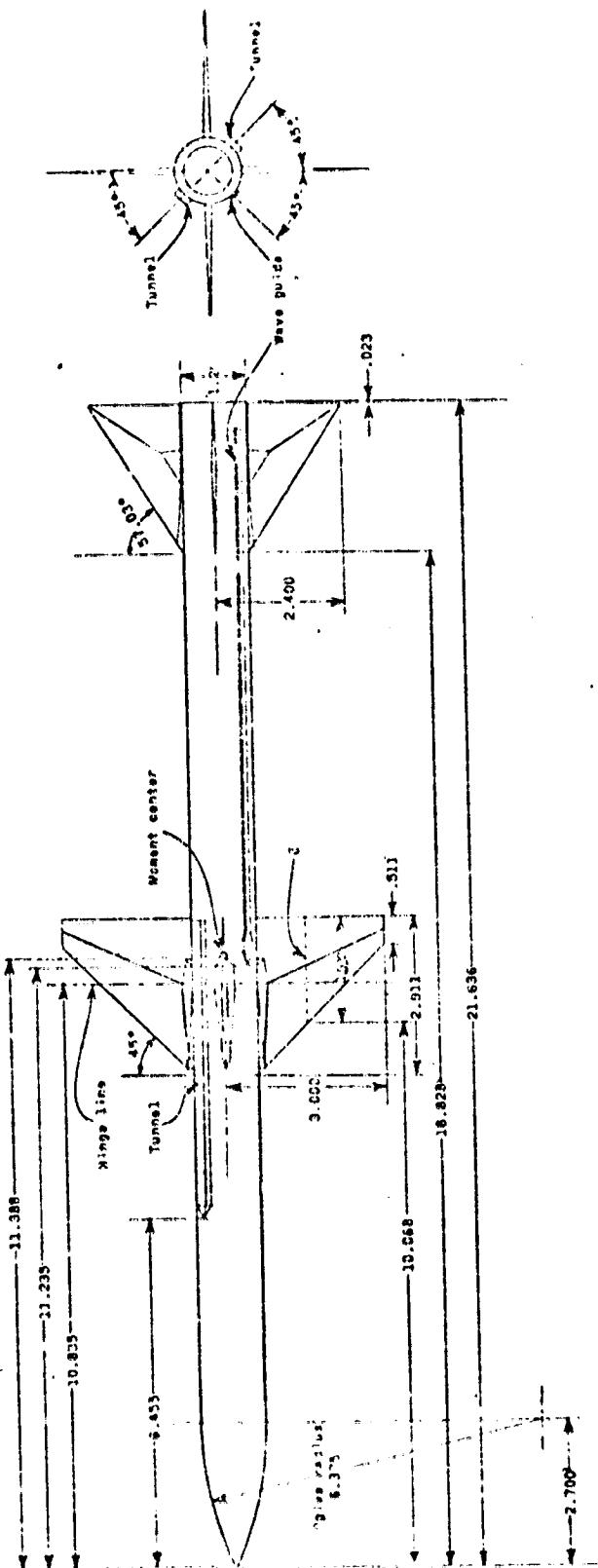
TM X-2831

DATA SUMMARIES

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AIR-TO-AIR MISSILES (AAM)

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Configuration with diamond airfoil sections.

Model details. Dimensions are in inches unless otherwise noted.

Ref. TM X 846

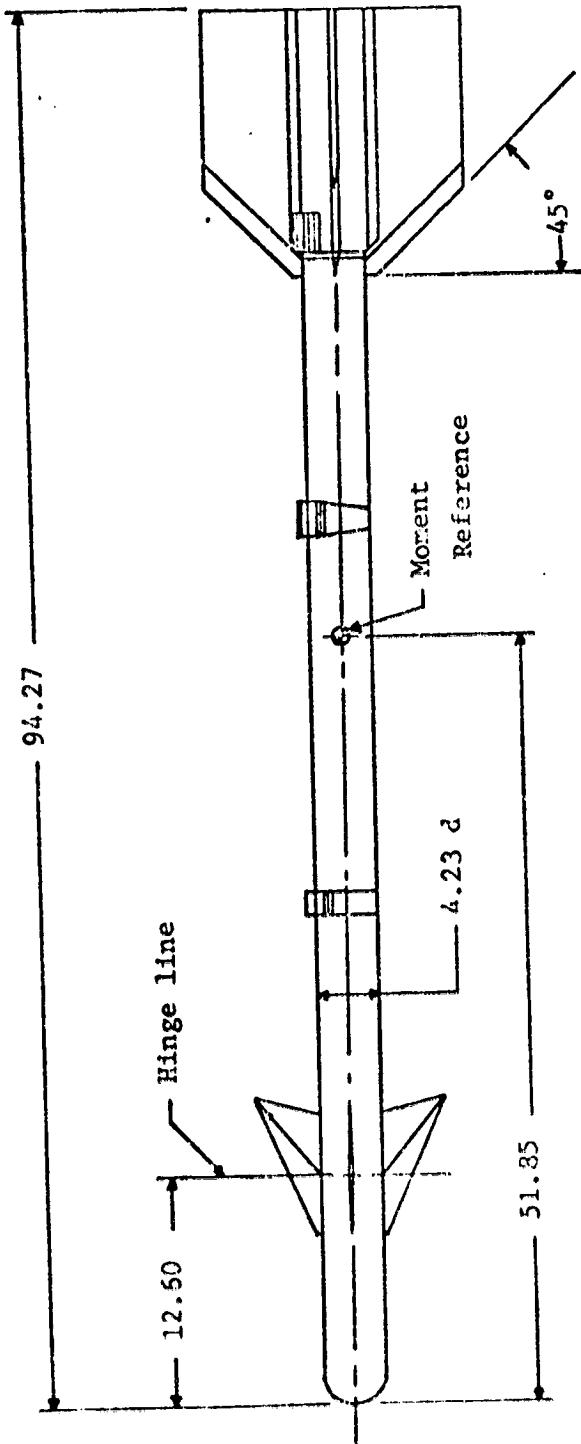
LONGITUDINAL PARAMETERS; $\alpha \approx 0^\circ$.

DIAMOND AIRFOIL

	M = 2.30		M = 4.60	
	$\phi=0^\circ$	$\phi=45^\circ$	$\phi=0^\circ$	$\phi=45^\circ$
$C_{N\alpha}$	0.592	0.568	0.454	0.373
$C_{M\alpha}$	-0.643	-0.440	-0.421	-0.146
$\frac{x_{ac}}{l}$	0.586	0.569	0.577	0.547
$C_{M\delta}$	0.267	0.427	0.026	0.090
$C_{N\delta}$	0.208	0.294	0.117	0.166

WEDGE AIRFOIL

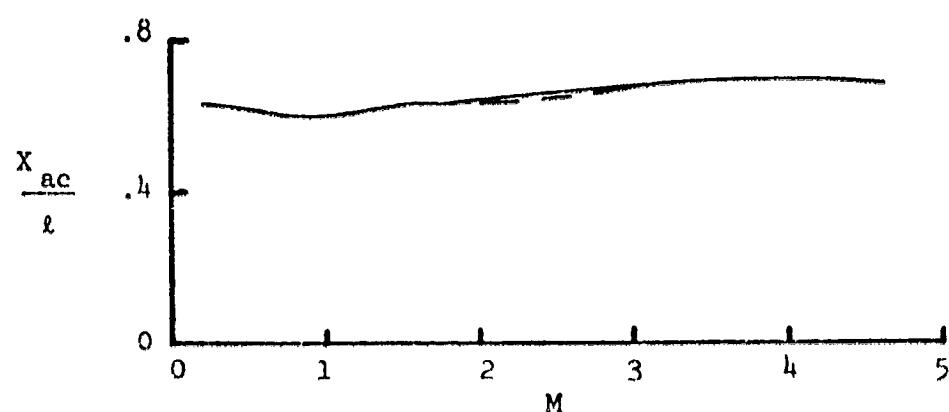
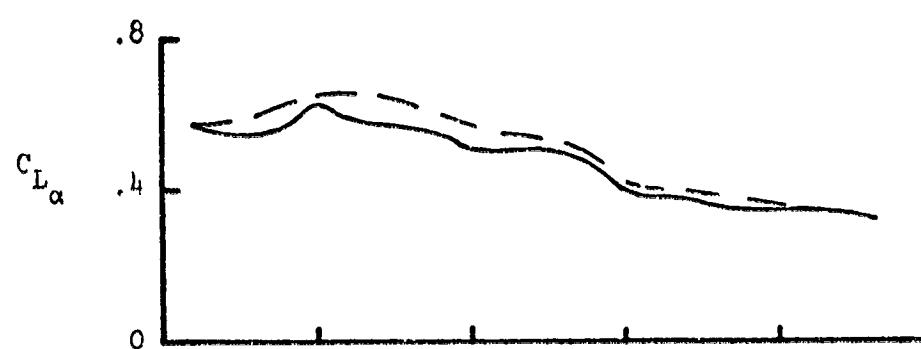
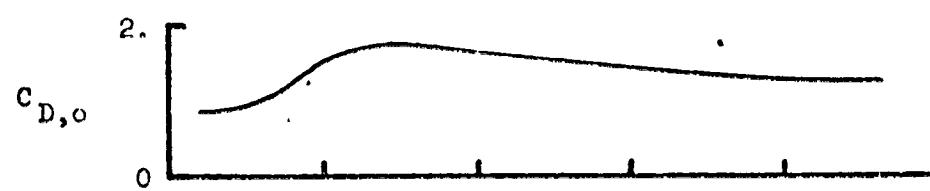
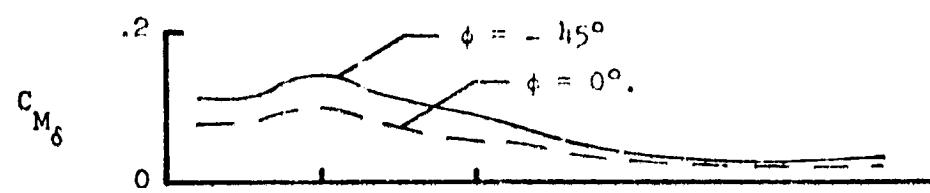
	M = 2.30		M = 4.60	
	$\phi=0^\circ$	$\phi=45^\circ$	$\phi=0^\circ$	$\phi=45^\circ$
$C_{N\alpha}$	0.568	0.547	0.424	0.374
$C_{M\alpha}$	0.589	-0.507	-0.626	-0.345
$\frac{x_{ac}}{l}$	0.584	0.577	0.608	0.577
$C_{M\delta}$	0.361	0.463	0.030	0.066
$C_{N\delta}$	0.199	0.304	0.145	0.210



Model drawing. $\phi = -90^\circ$. (All dimensions are in centimeters.)

Ref. TM X-3070

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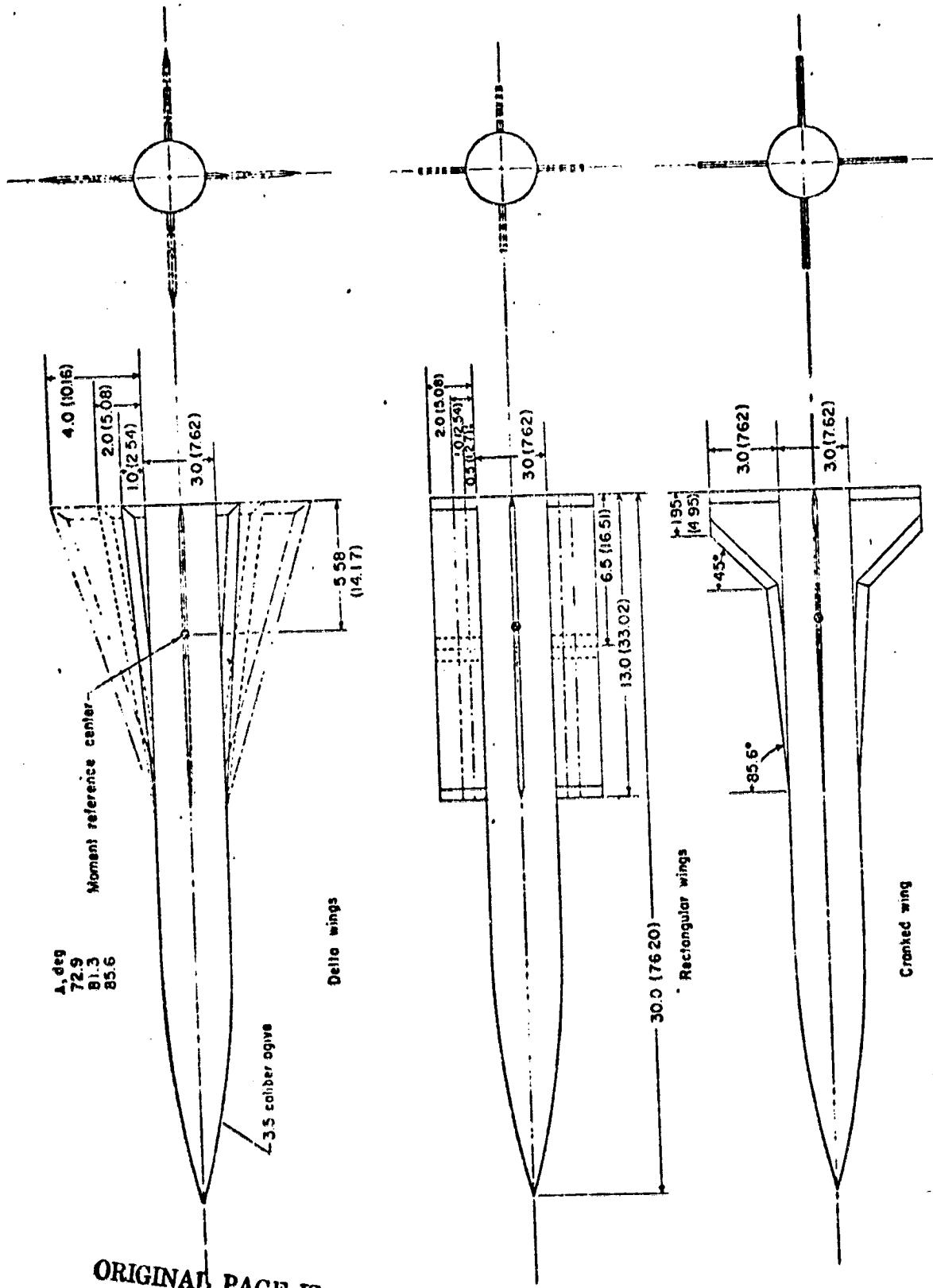
Variation of longitudinal parameters with Mach number; $\alpha=0^\circ$.

Ref. TM X-3070

SURFACE-TO-AIR MISSILE (SAM)

OR

AIR-TO-AIR MISSILE (AAM)

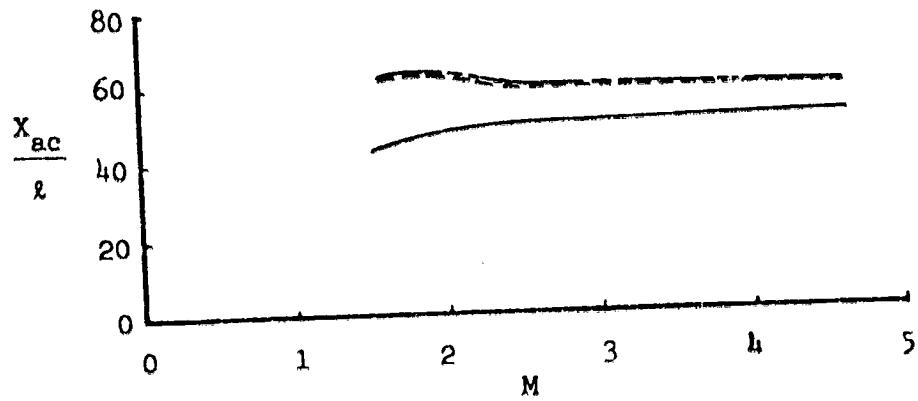
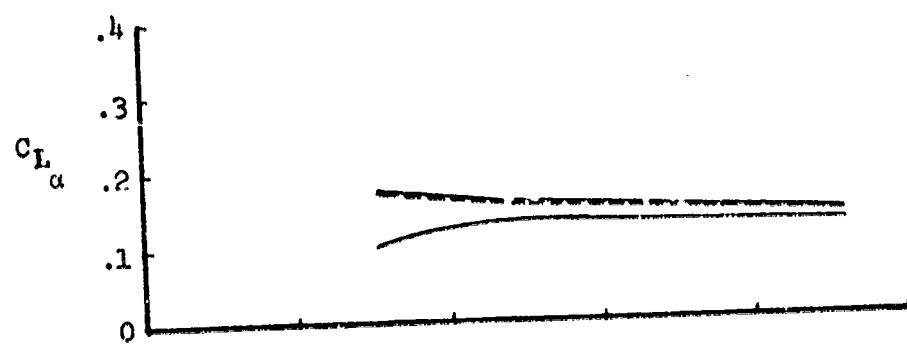
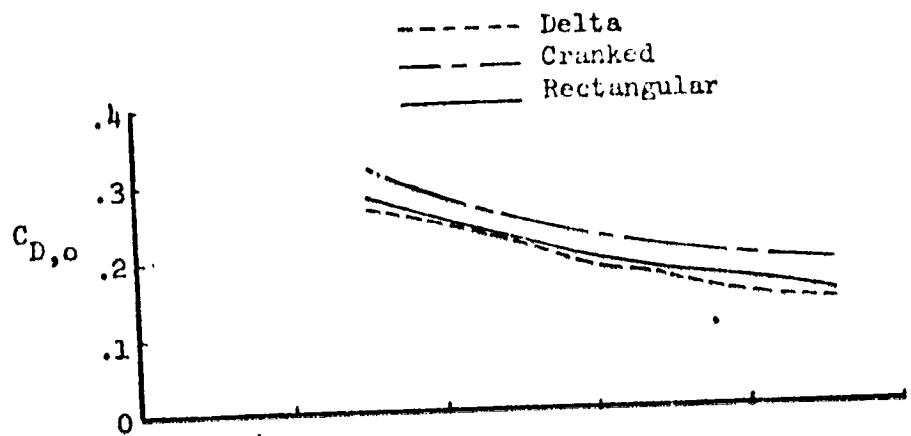


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Details of models. Dimensions given first in inches and parenthetically in centimeters.

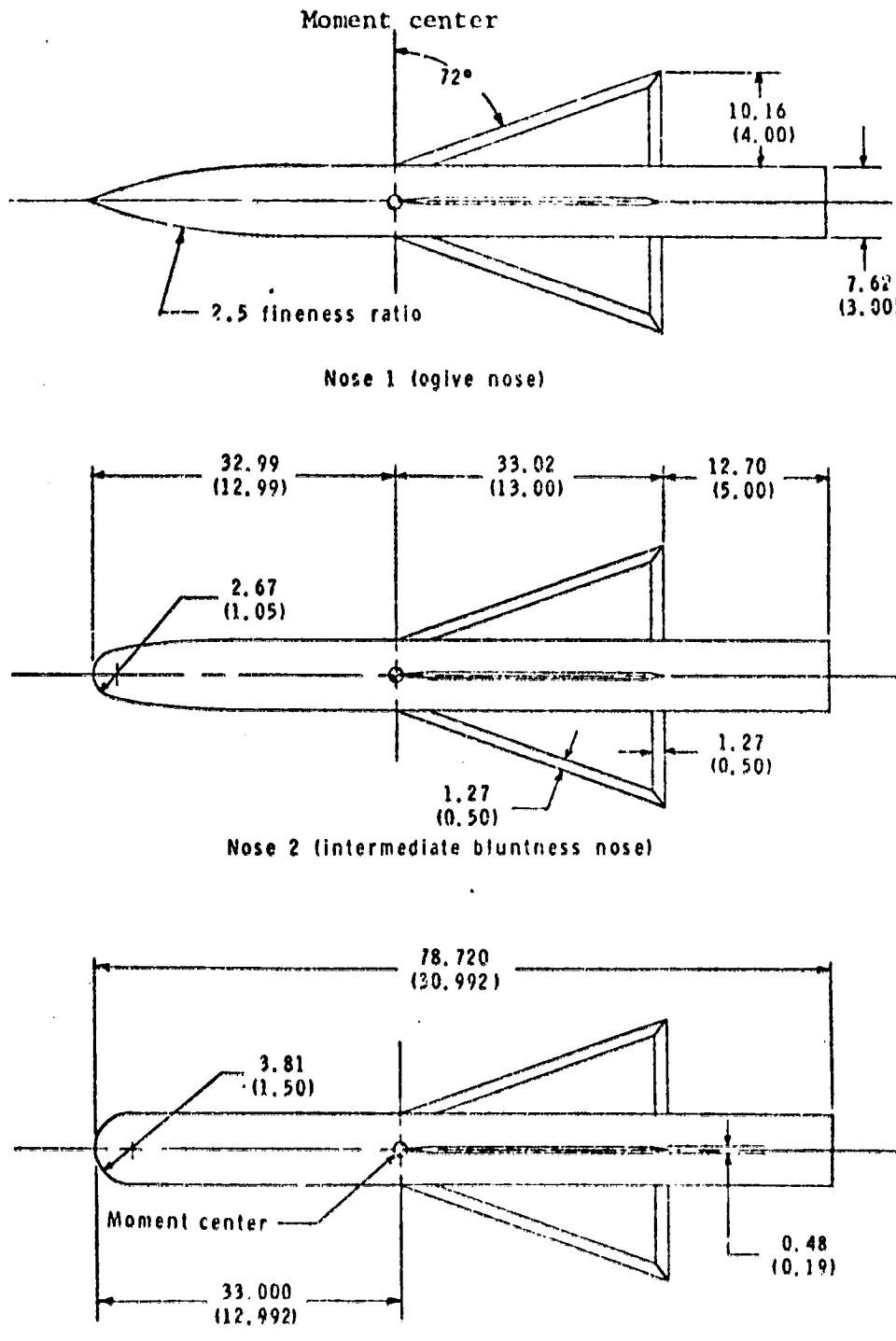
Ref. TM X-1839

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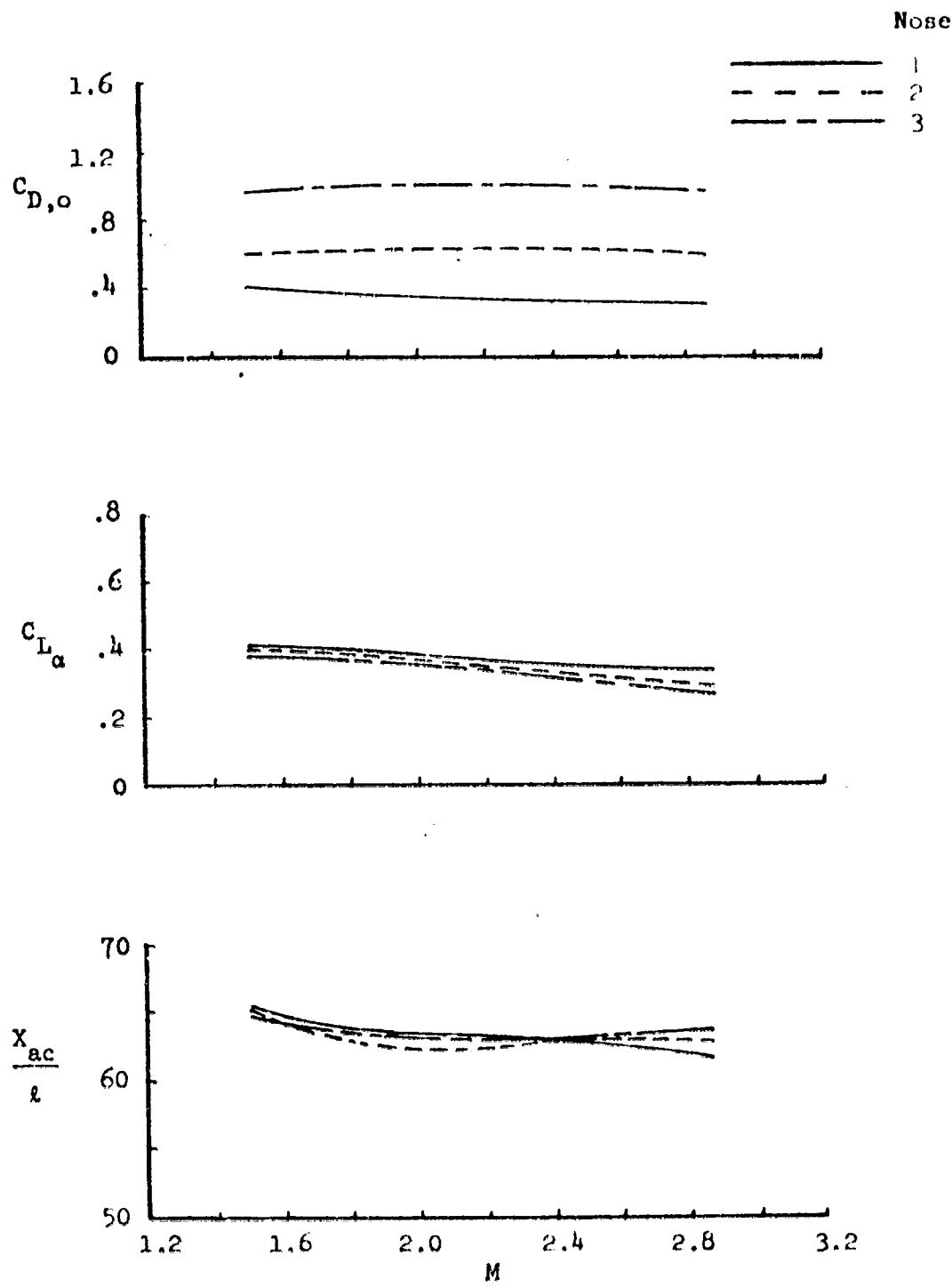


Variation of longitudinal parameters with Mach number, $\alpha=0$,
 $\phi=0$, mid-sized wings.

Ref. TM X-1839

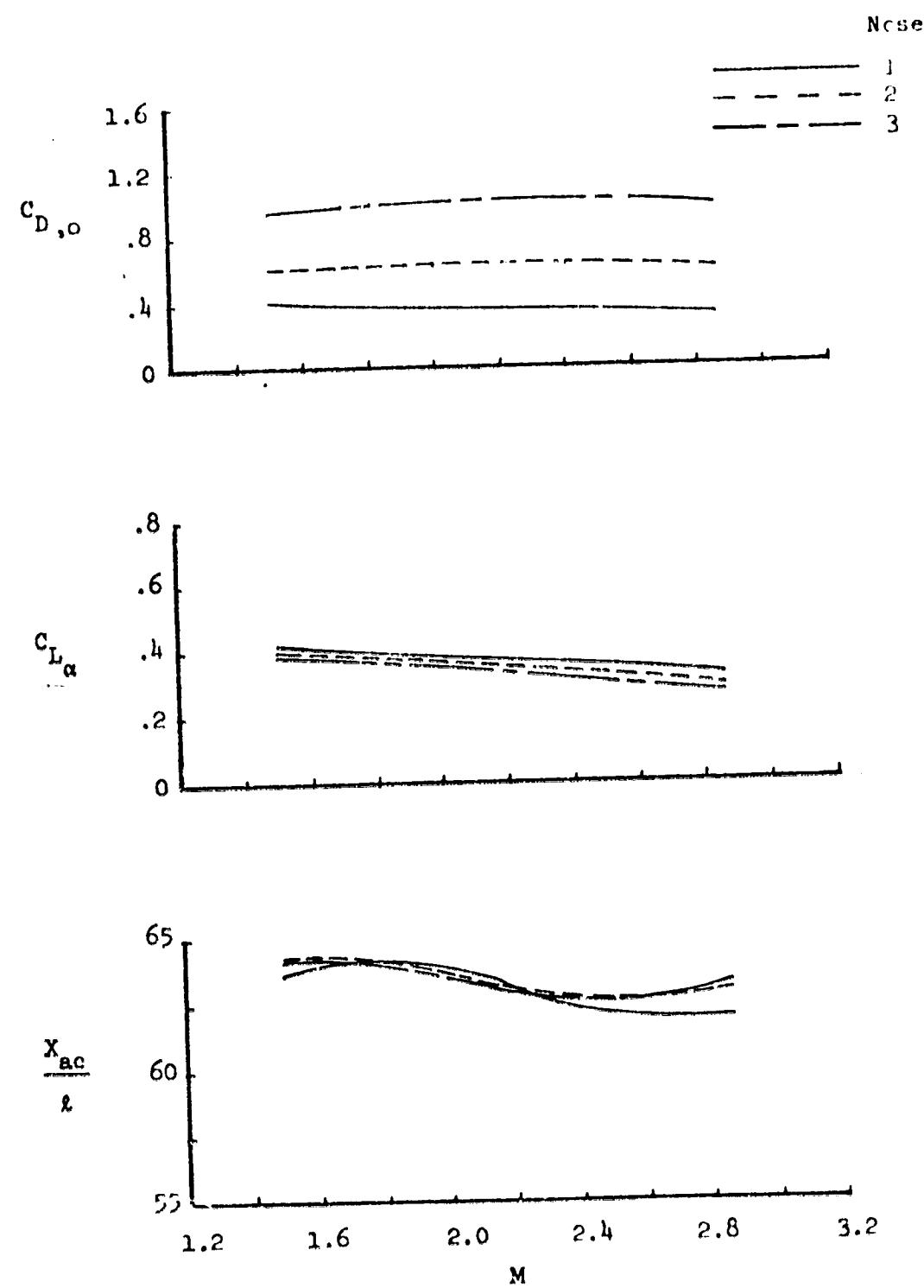


Drawing of model showing nose shapes investigated. Linear dimensions are given in centimeters and parenthetically in inches.



Variation of longitudinal parameters with Mach number, $\alpha=0$,
 $\phi=0$

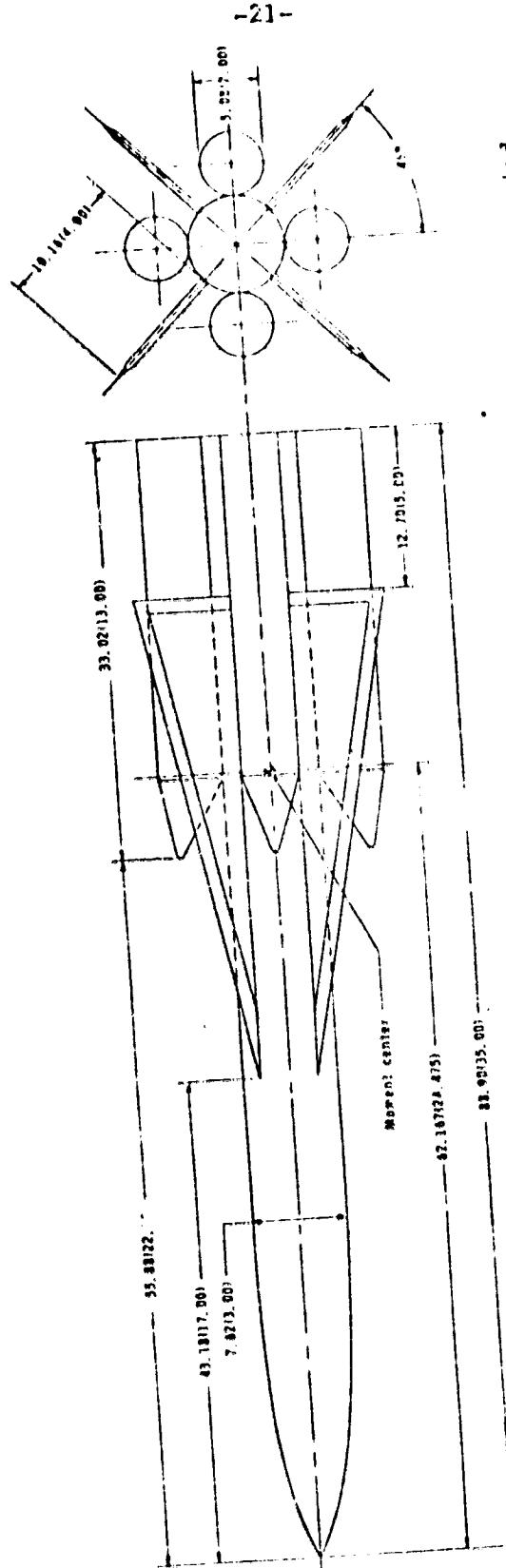
-20-



Variation of longitudinal parameters with Mach number, $\alpha=0$
 $\phi=45^\circ$

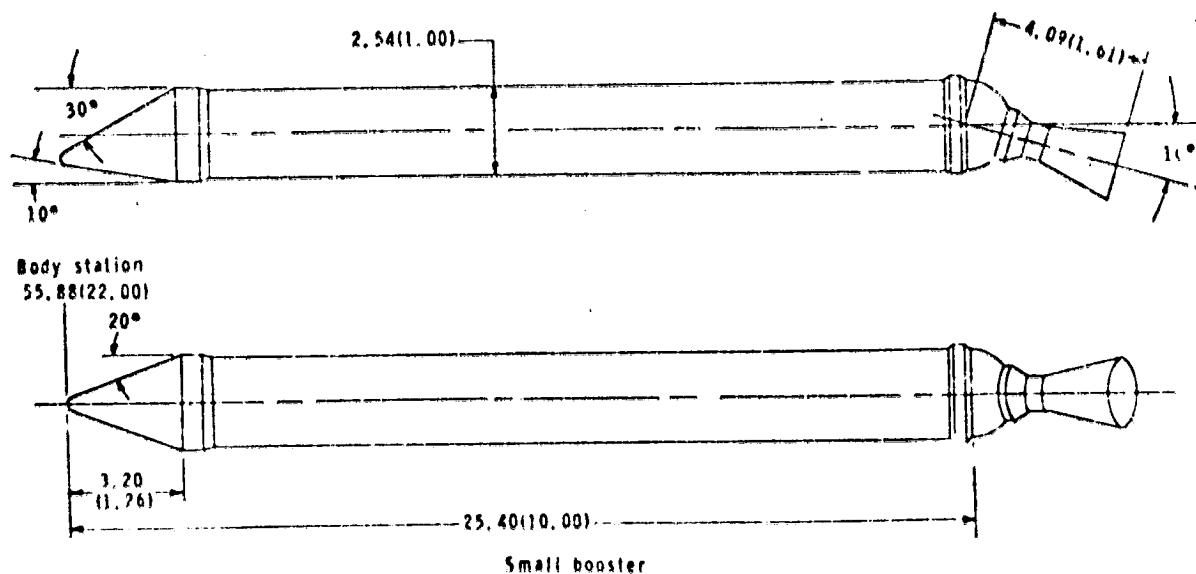
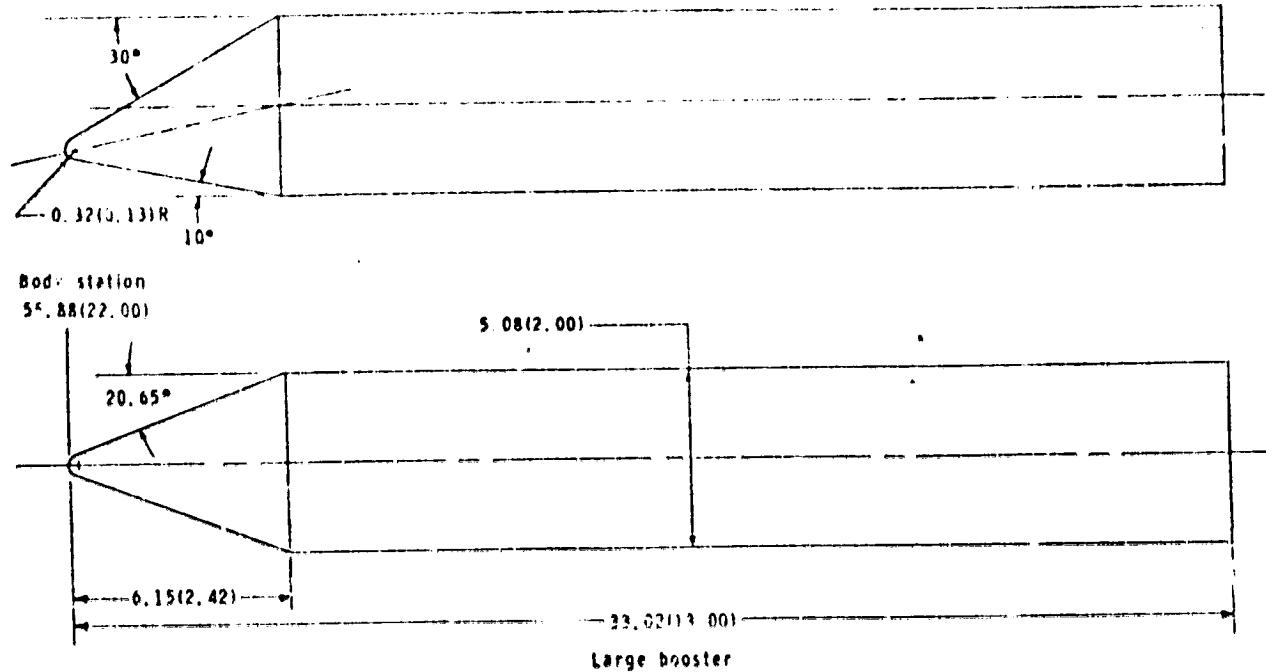
Ref. TM X-2289

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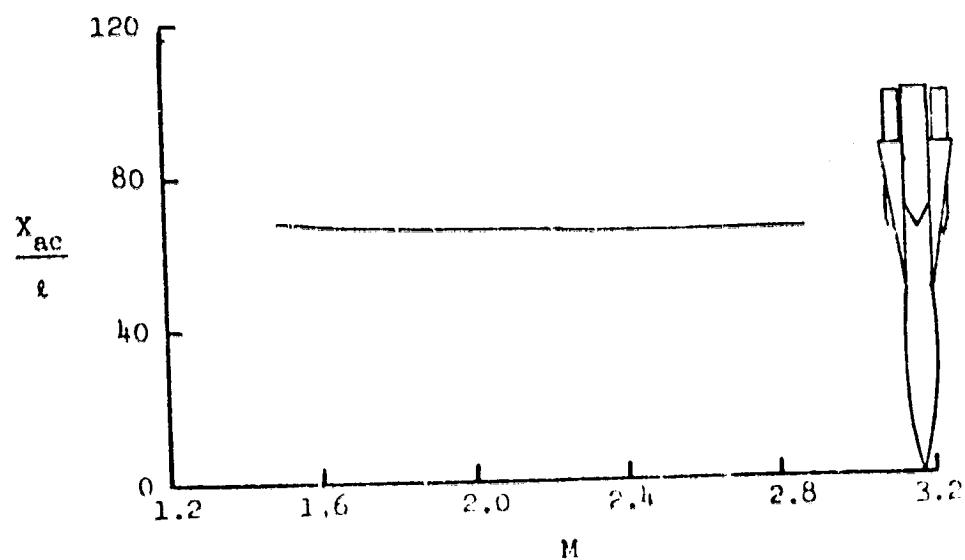
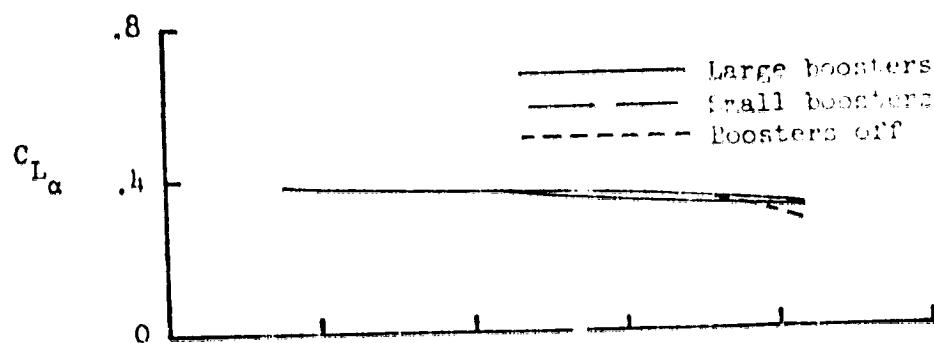
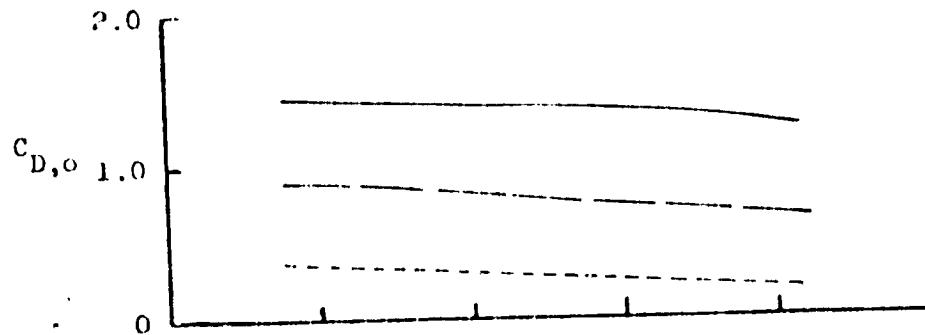
Drawing of model. Dimensions are in centimeters (inches) unless otherwise noted.

Ref. TM X-2491



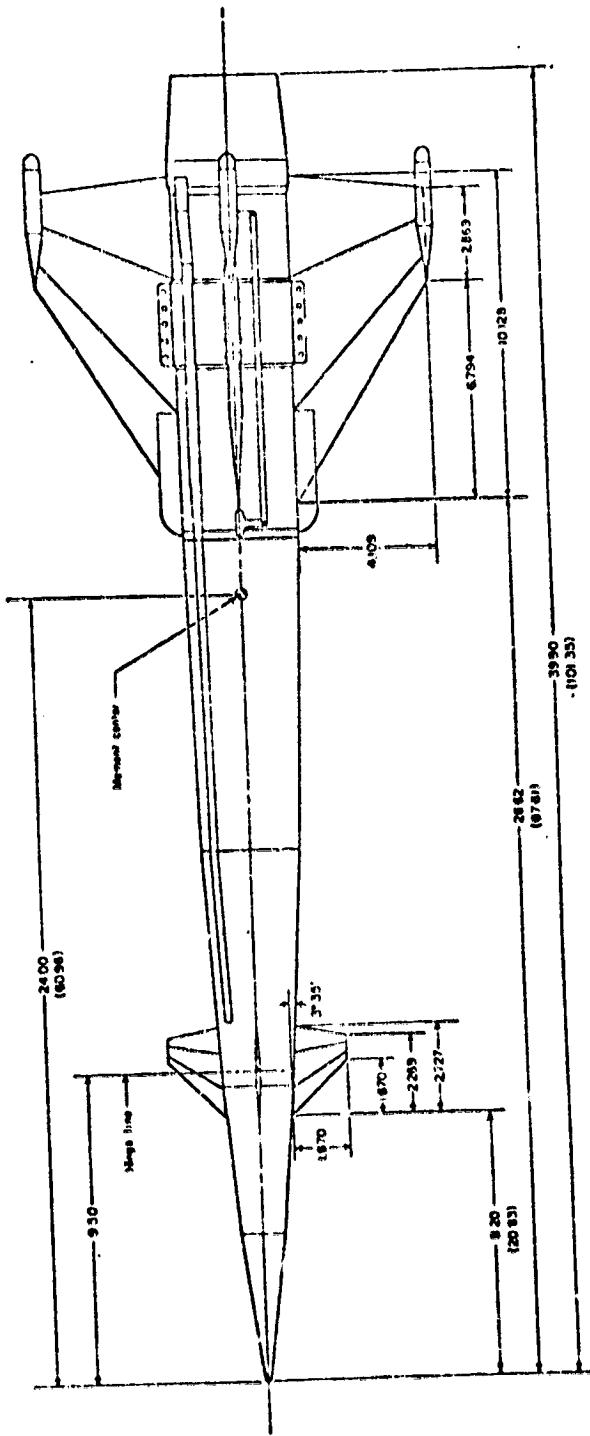
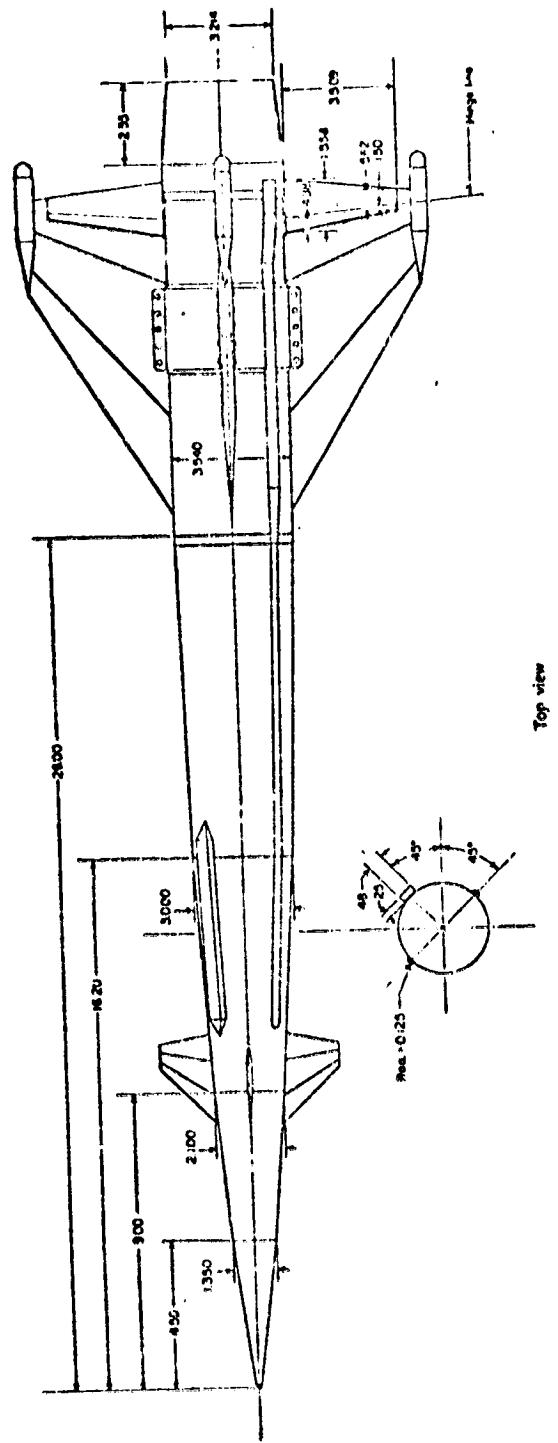
Concluded.

Ref. TM X-2491



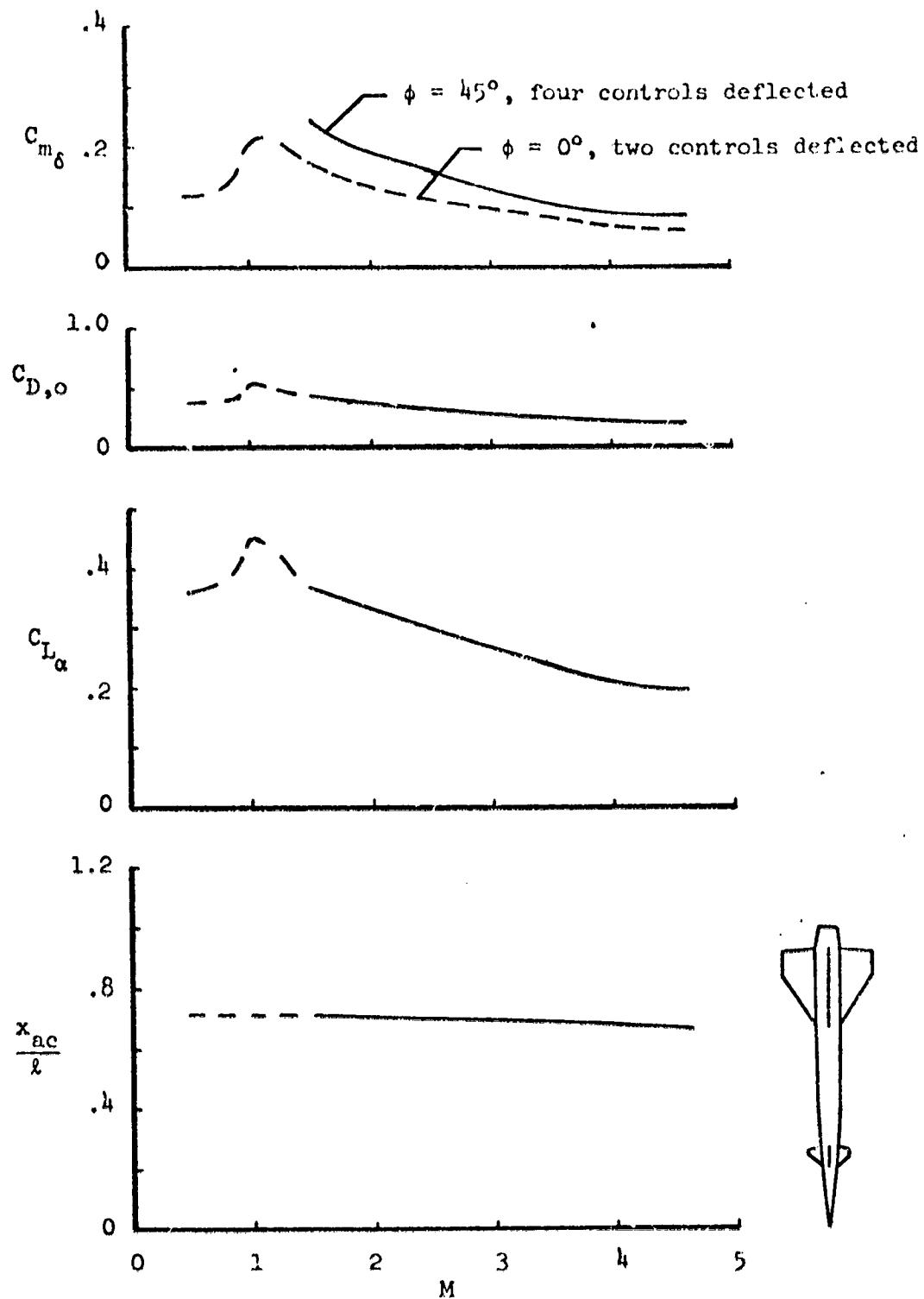
Variation of longitudinal parameters with Mach number; $\alpha = 0^\circ$.

Ref. TM X-2491



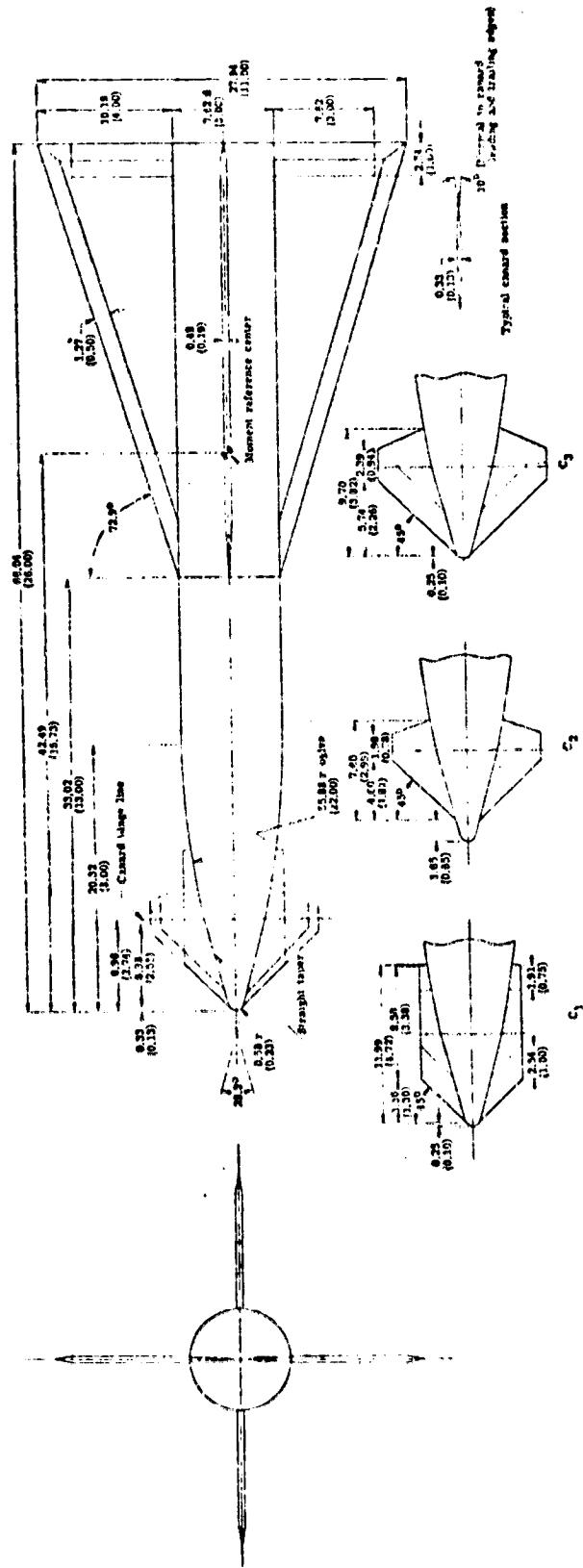
such as surfaces oriented in the roll plane.

Ref: TM X-13C9, TM X-1352

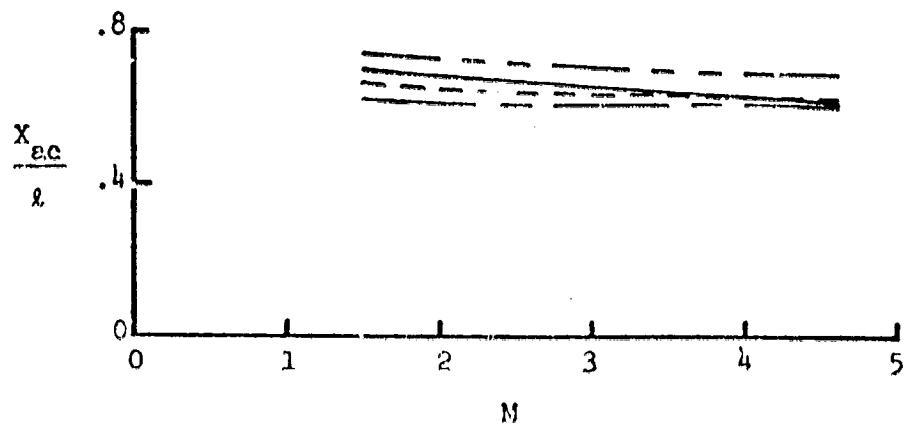
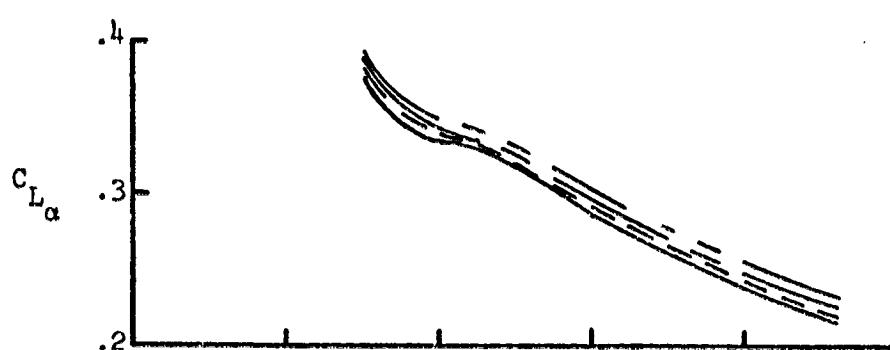
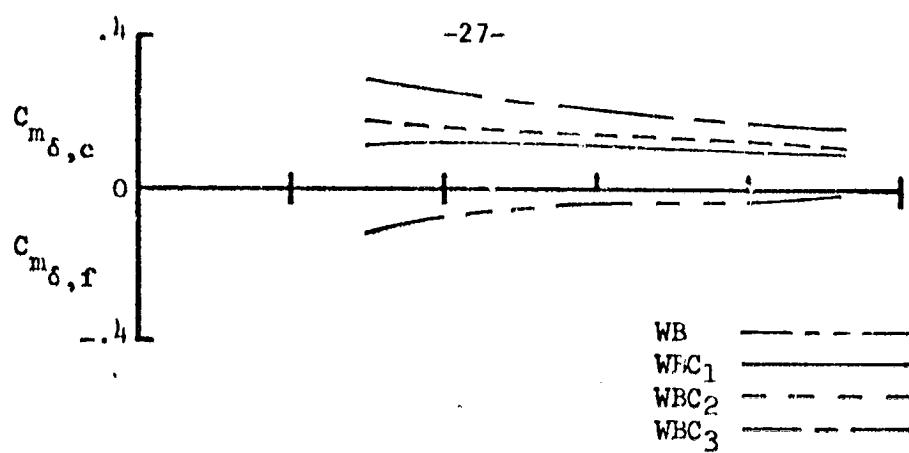


Variation of longitudinal parameters with Mach number; $\alpha=0$.

Ref. TM X-1309, TM X-1352



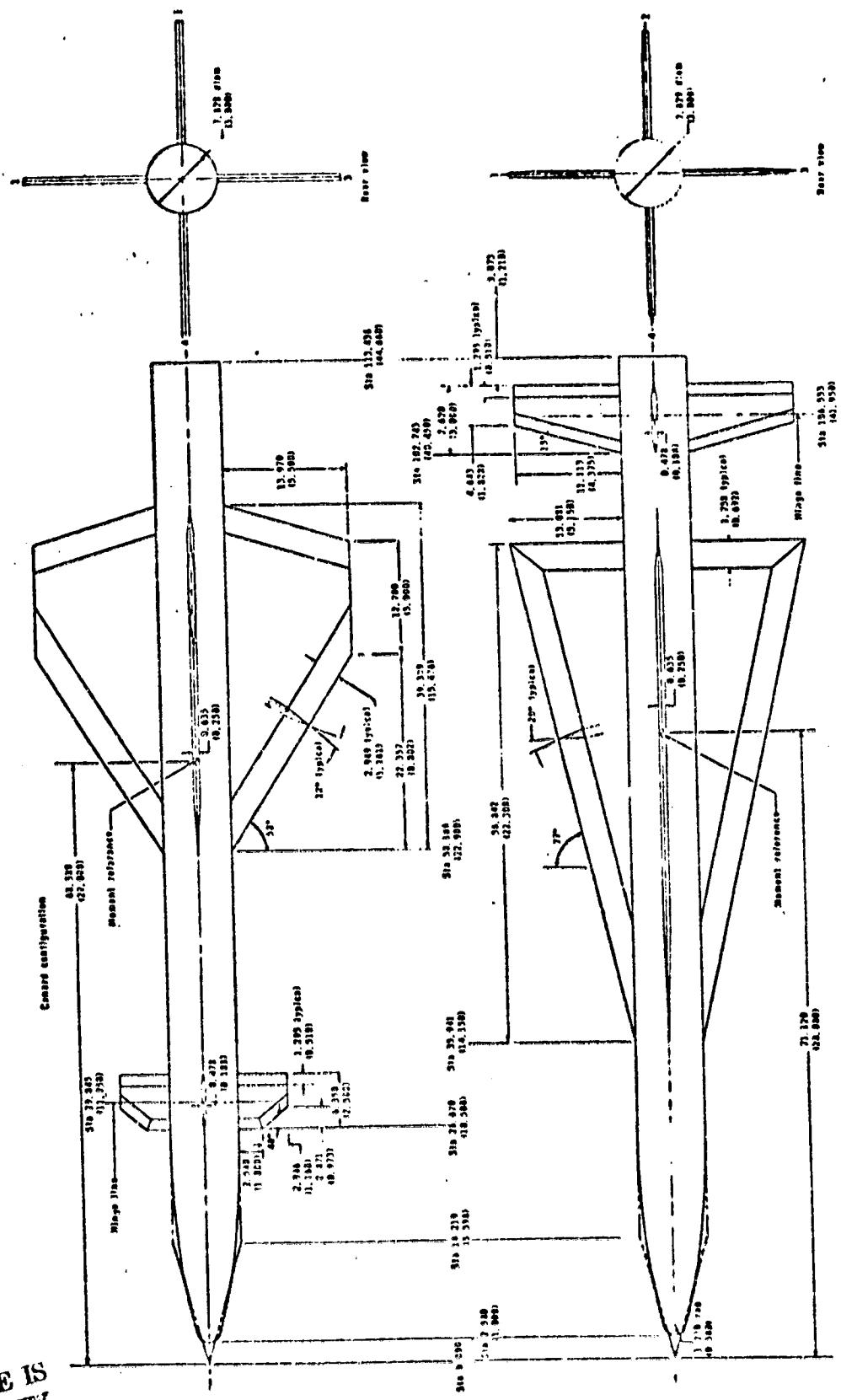
-27-



Variation of longitudinal parameters with Mach number; $\alpha=0^\circ$

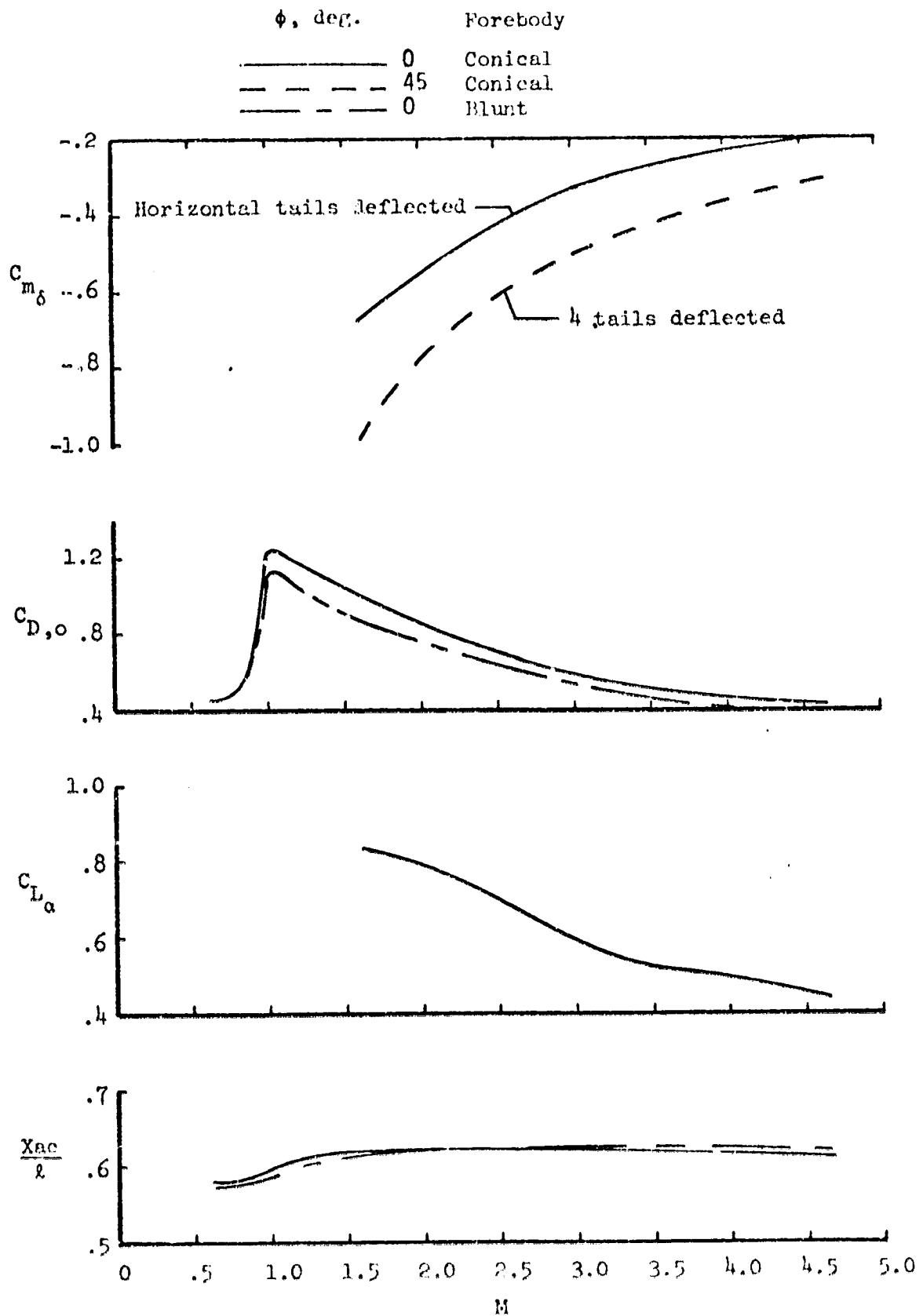
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Model details. All dimensions are in centimeters (inches) unless otherwise indicated.

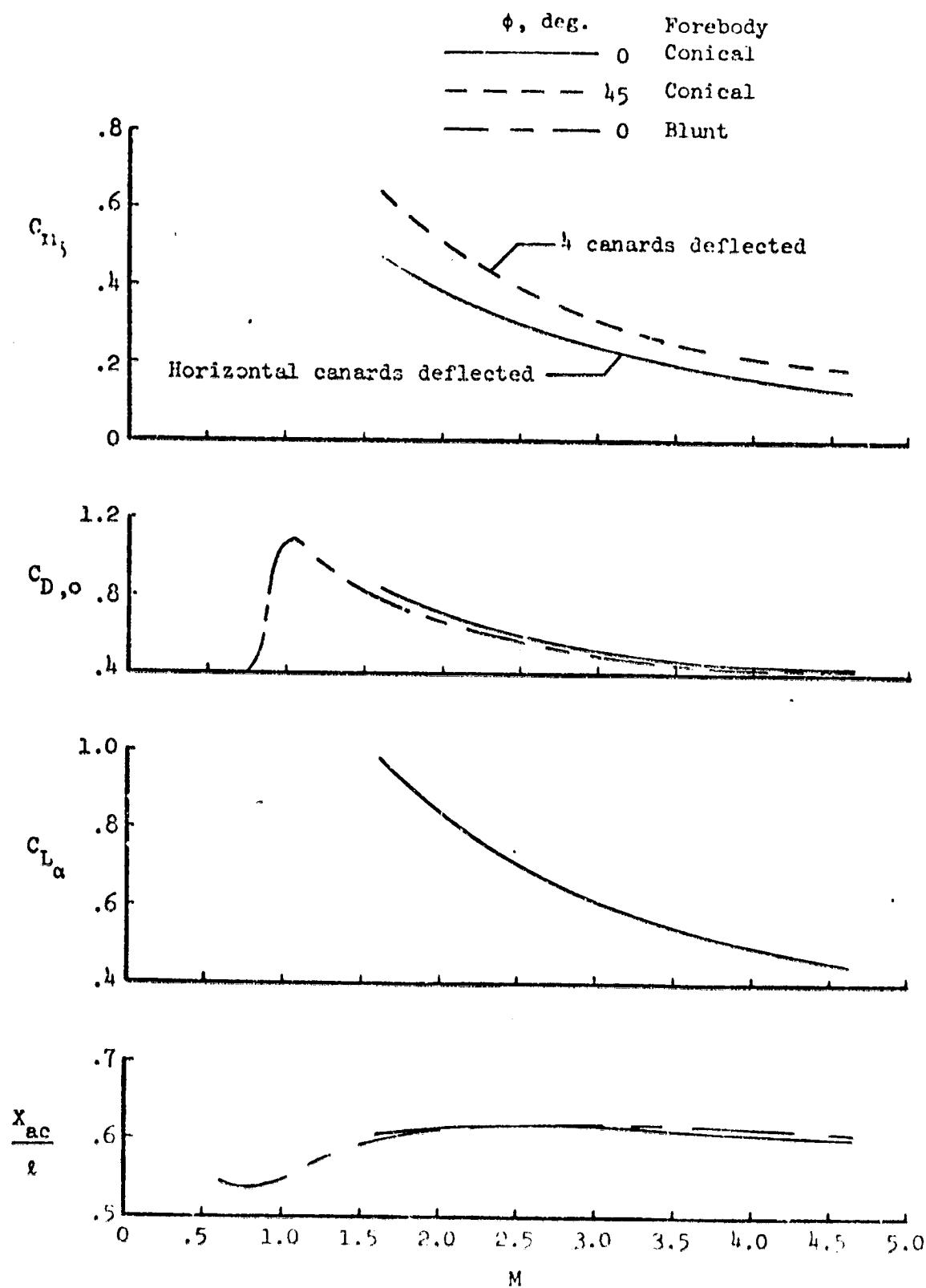
Ref. TM X-2780



Variation of longitudinal parameters with Mach number; $\alpha=0$.

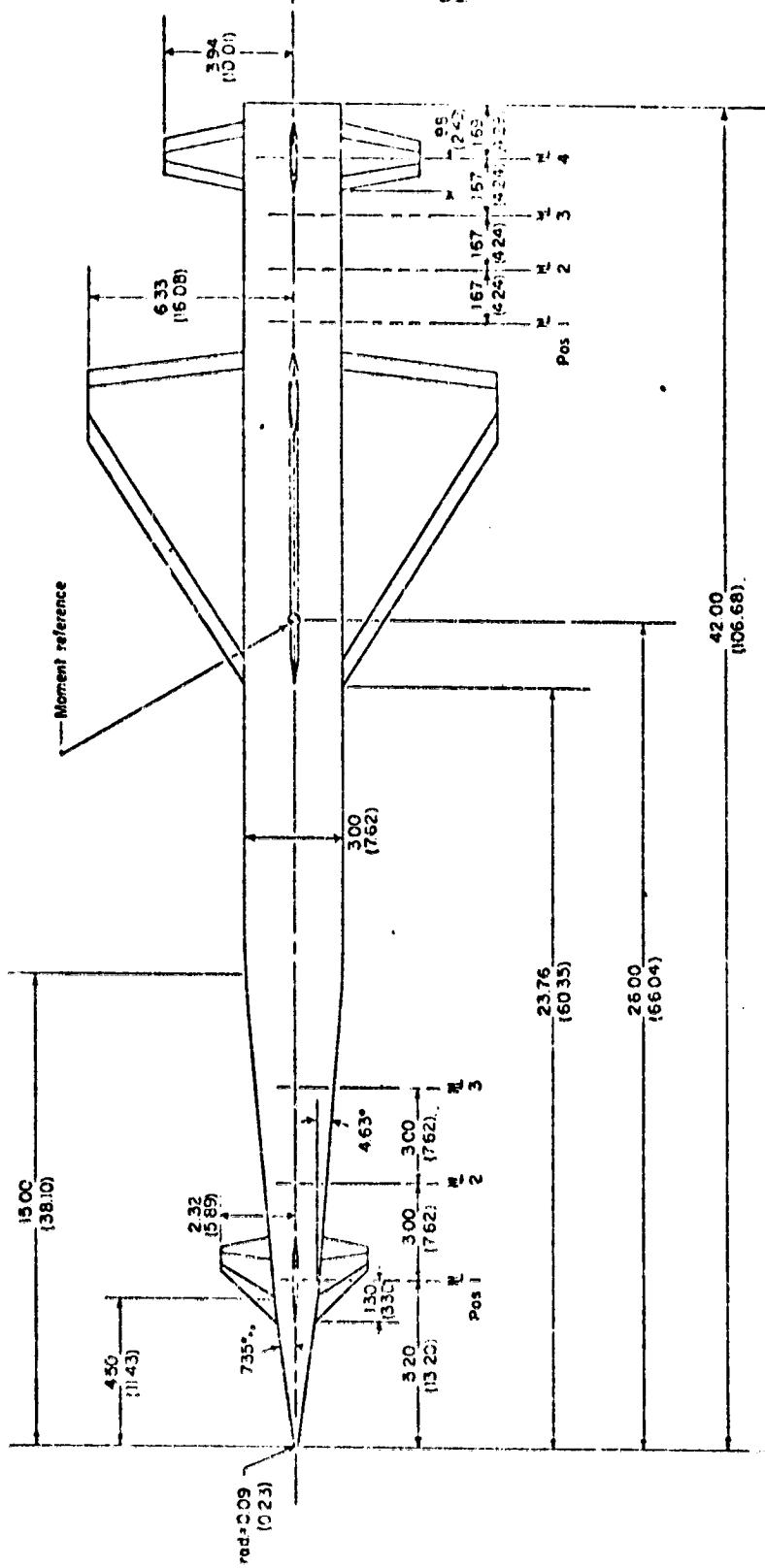
Ref. TM X-2780

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Variation of longitudinal parameters with Mach number; $\alpha=0$.

Ref. TM X-2/80

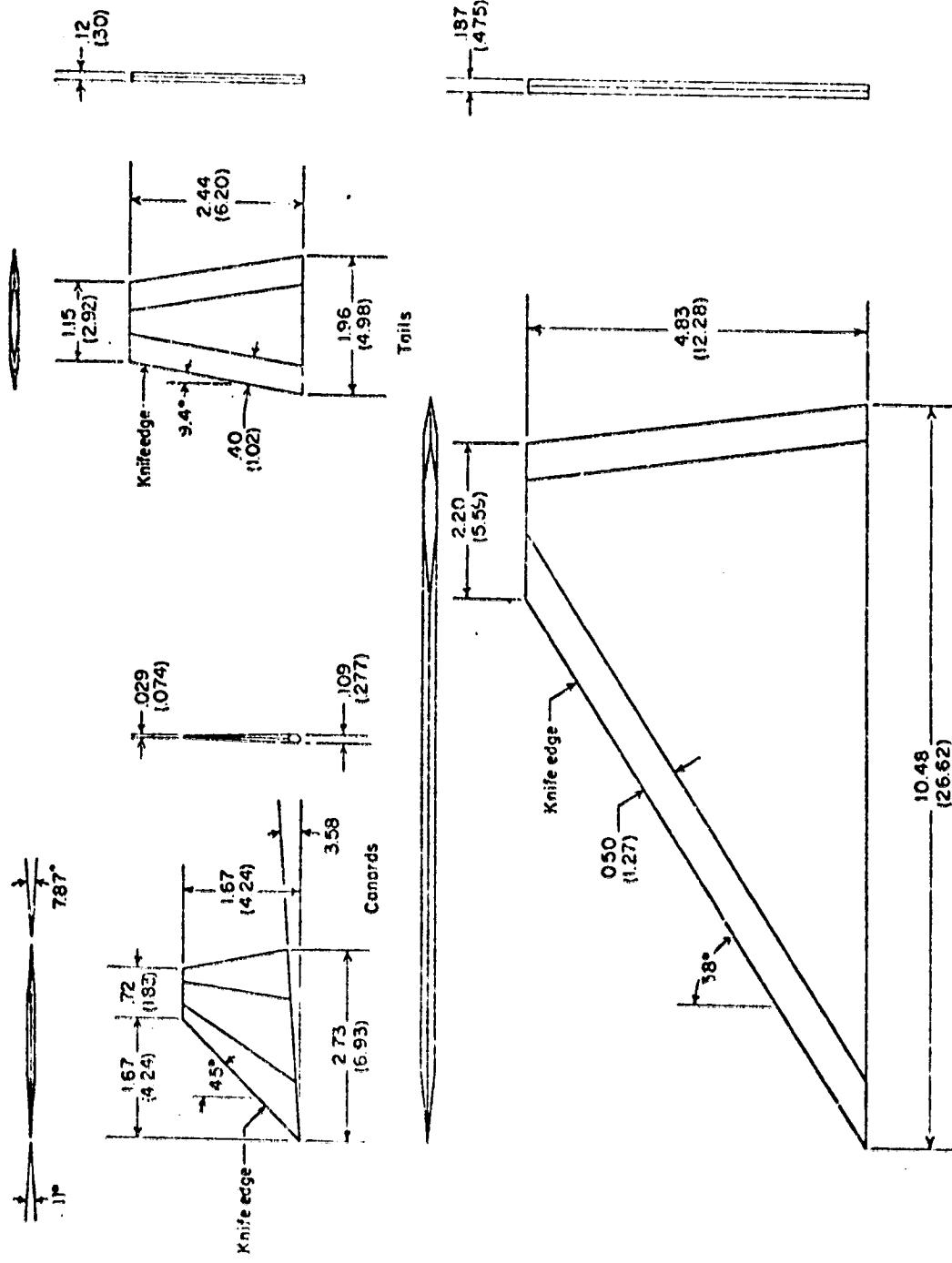


(a) Complete model.

Model drawings. (All dimensions are given in inches and parenthetically in centimeters.)

Ref. TM X-1834

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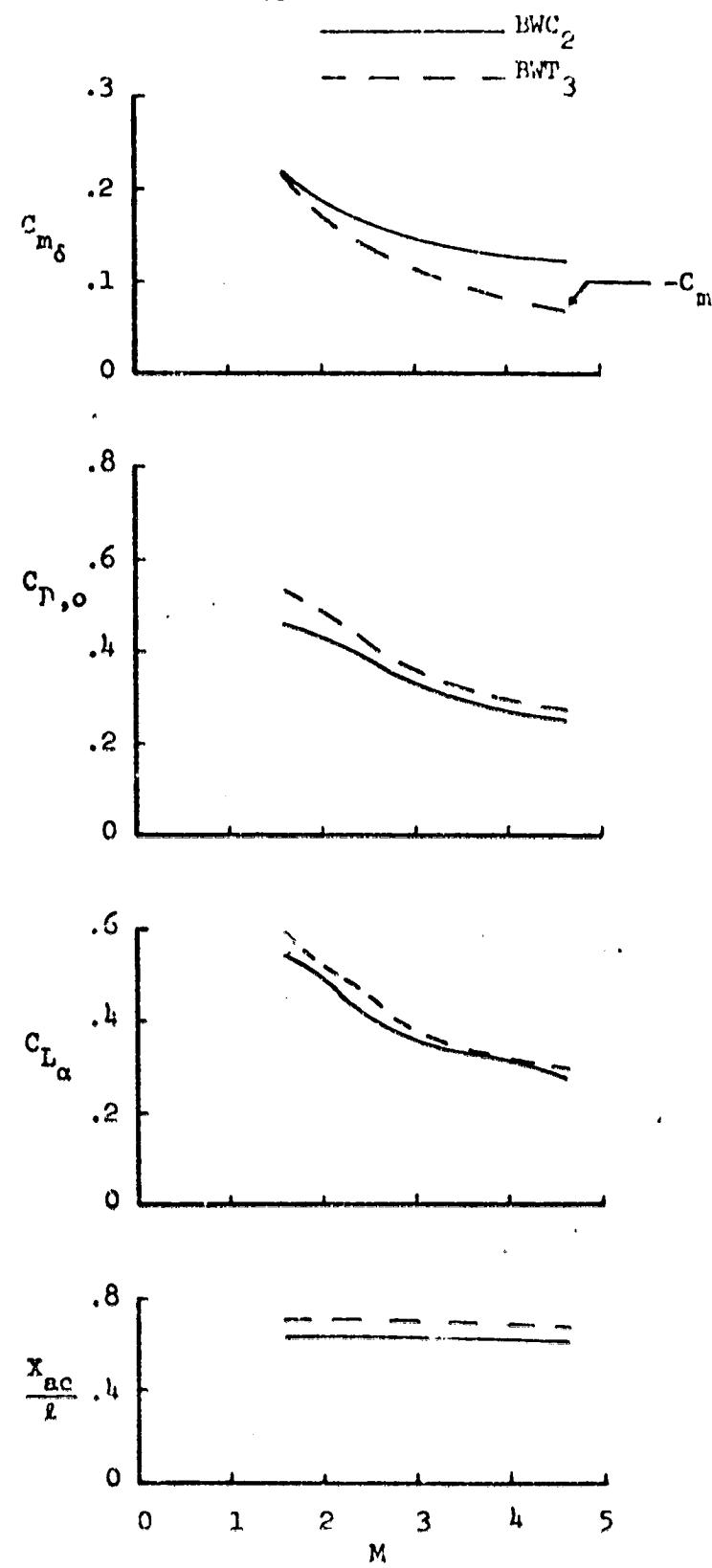


(b) Details of canards, tails, and wing.

Ref. TM X-1834

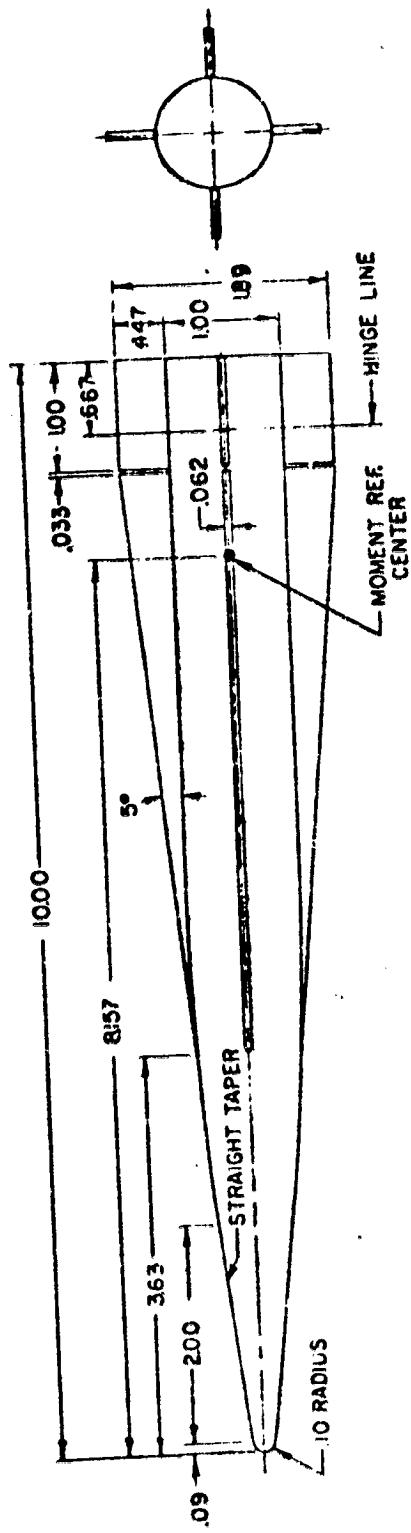
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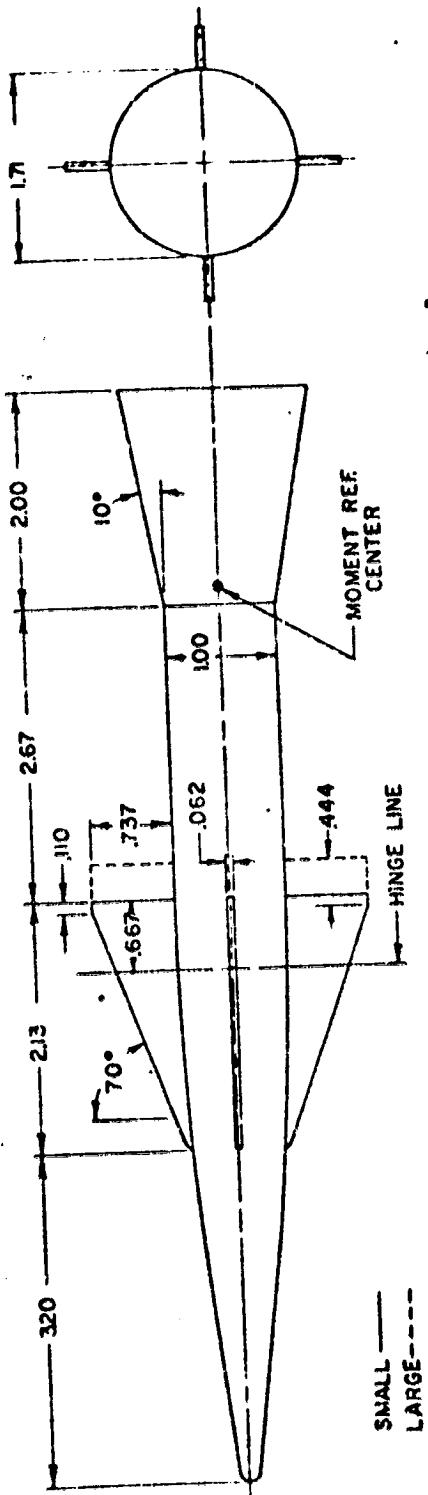


Variation of longitudinal parameters with Mach number; $\alpha=0.$

Ref. TM X-18-4



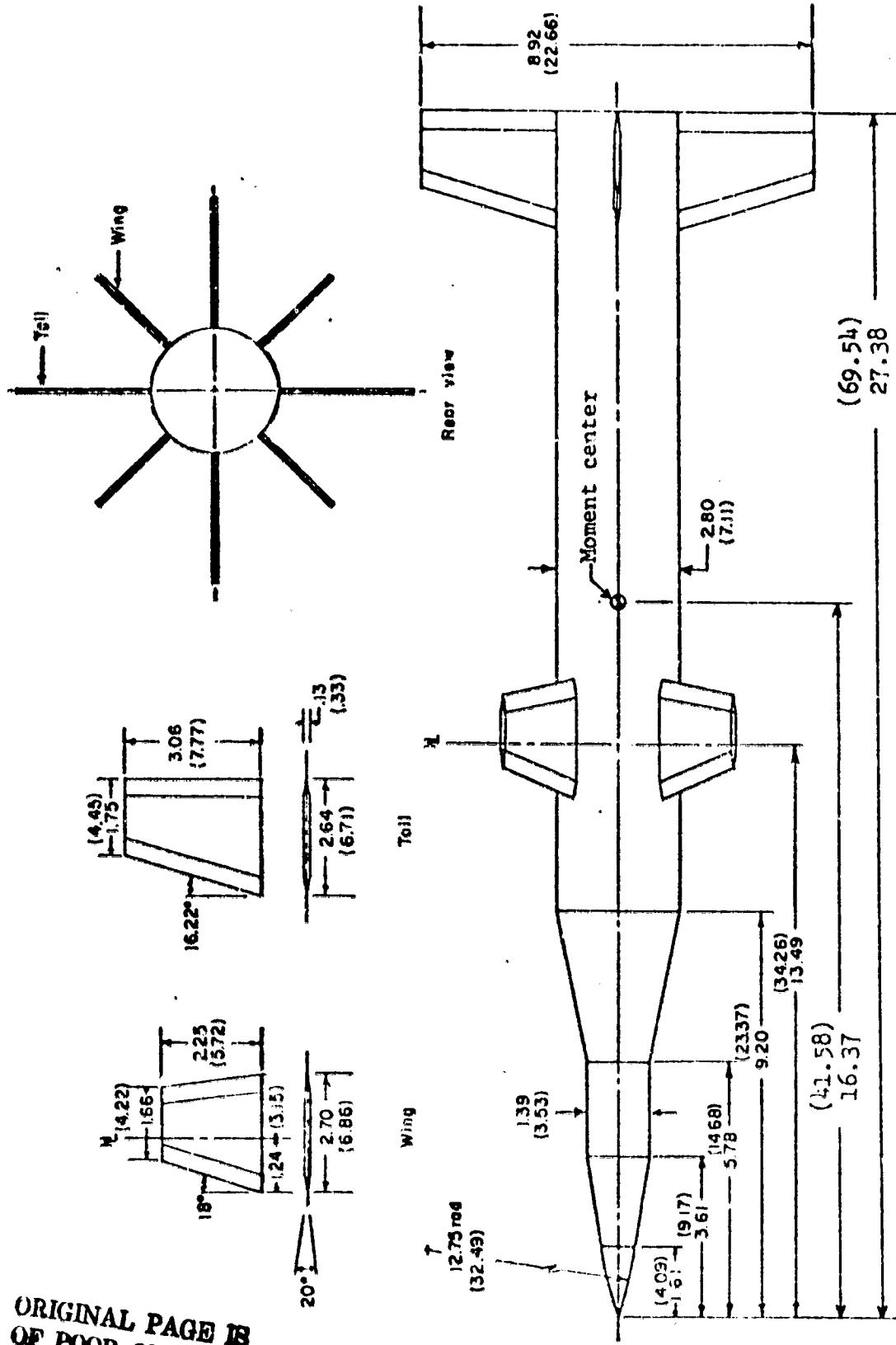
(a) Model with delta fins and trailing-edge controls.



(b) Model with flared skirt and large and small canard controls.
Missile configurations tested. All linear dimensions are in diameters.

LONGITUDINAL PARAMETERS AT MACH NUMBER 4.55; $\alpha=0^\circ$.

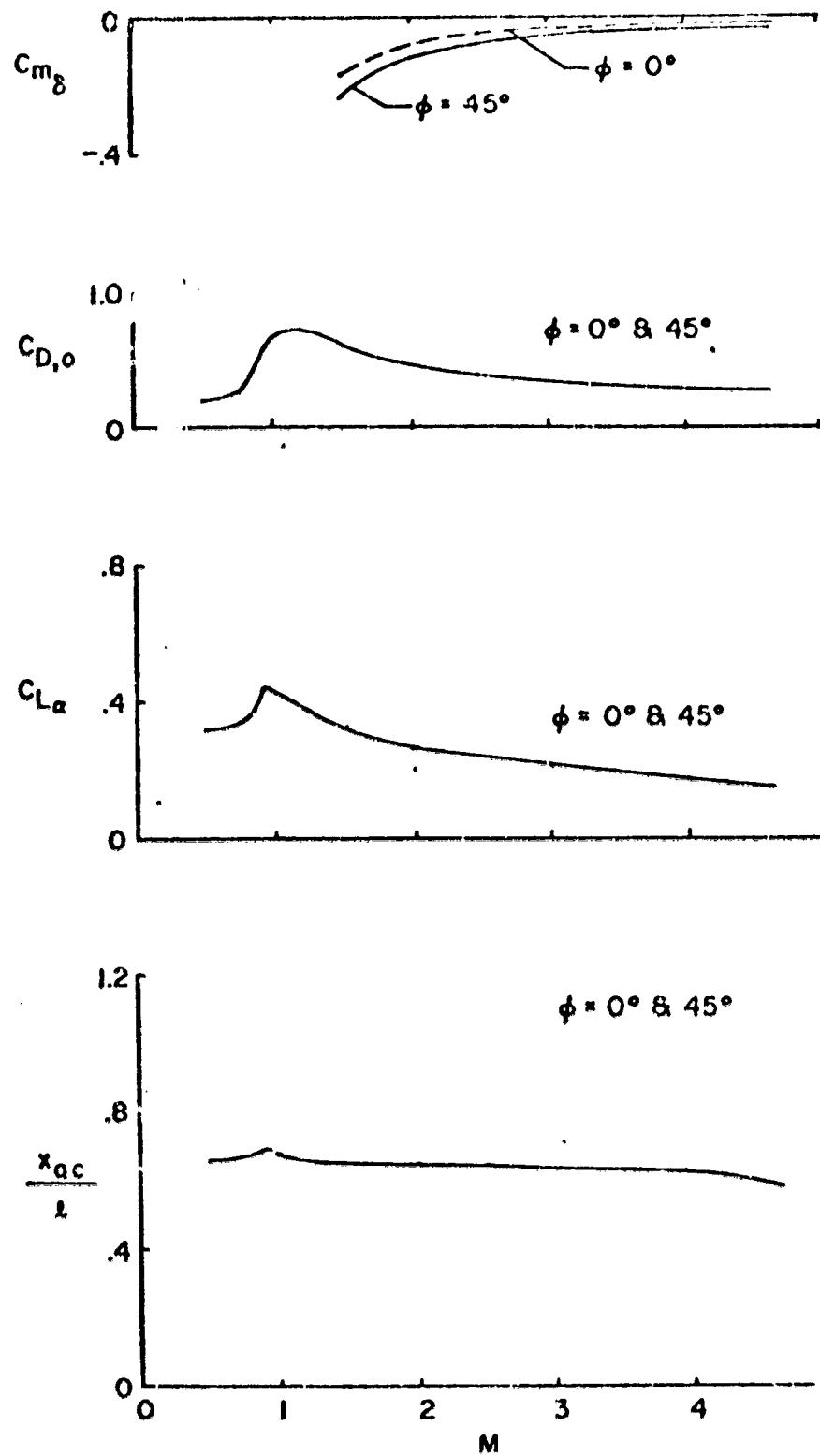
CONFIGURATION	$C_{m\delta}$	$C_{D,\alpha}$	$C_{L\alpha}$	$\frac{X_{ac}}{\ell}$
Delta Fins and Trailing-Edge Controls	-0.017	0.12	0.134	0.637
Large Canard Controls with Flared Skirt	0.166	0.36	0.175	0.593
Small Canard Controls with Flared Skirt	0.143	0.34	0.150	0.583
Small Canard Controls without Flared Skirt	—	0.18	0.105	0.445



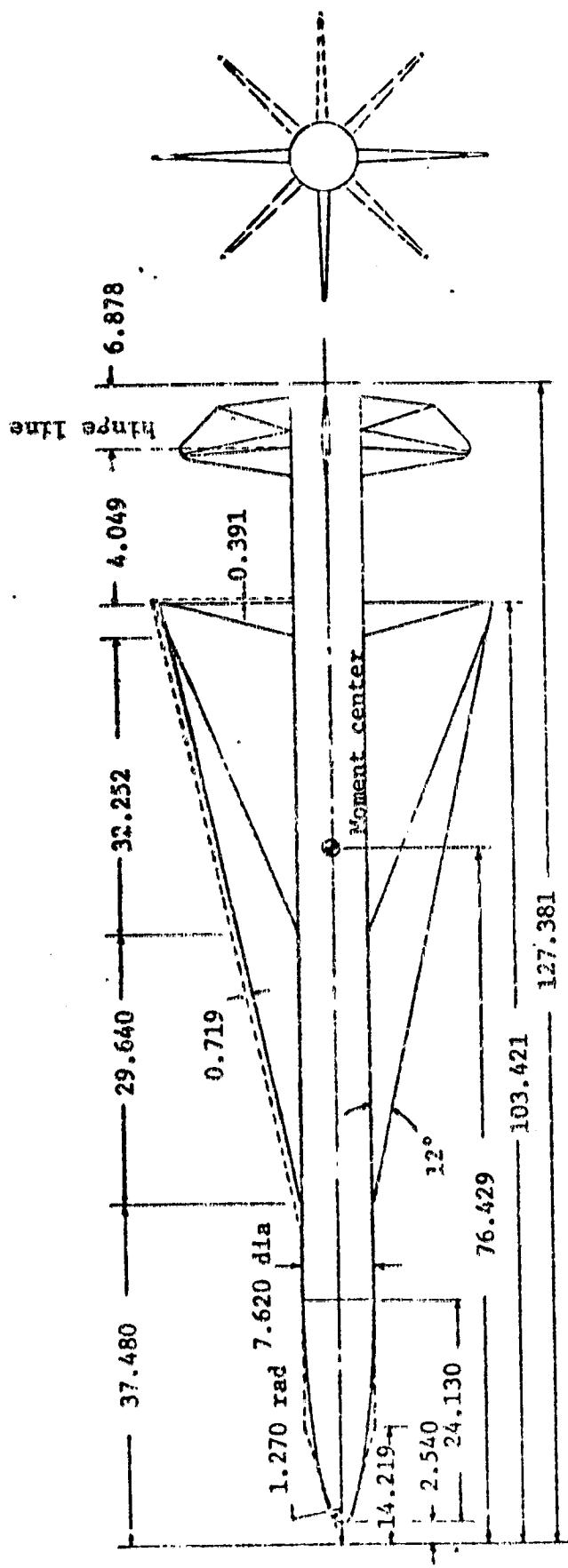
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Details of model. Linear dimensions are in inches (values within parentheses are centimeters).

Ref. TM X-1184, TM X-1332

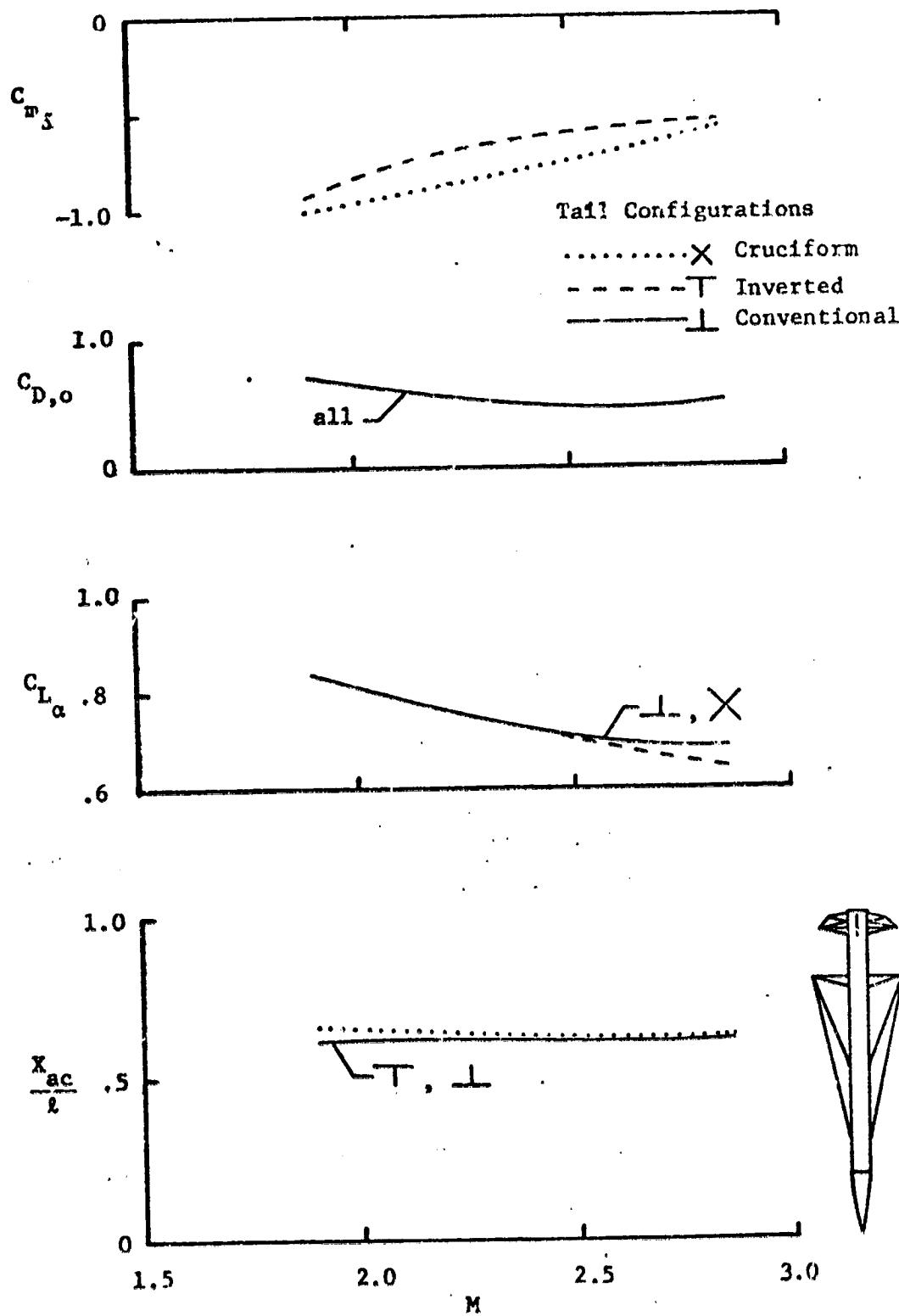


Variation of longitudinal parameters with Mach numbers; $\alpha=0$.



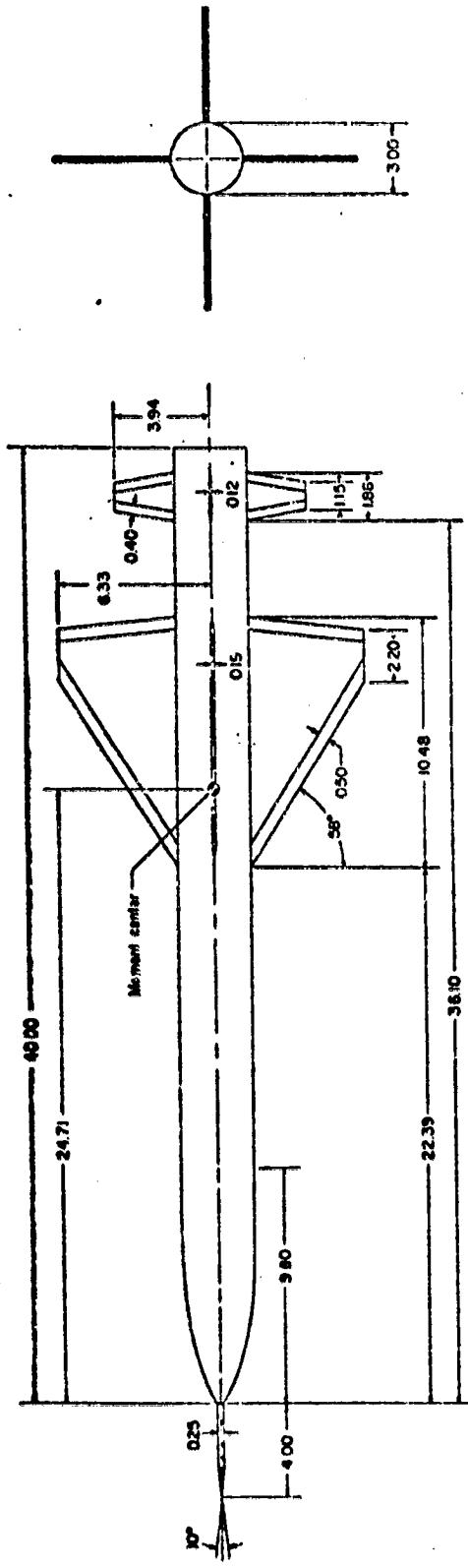
Model drawings. Linear dimensions are in centimeters.

Ref. TM X-71984



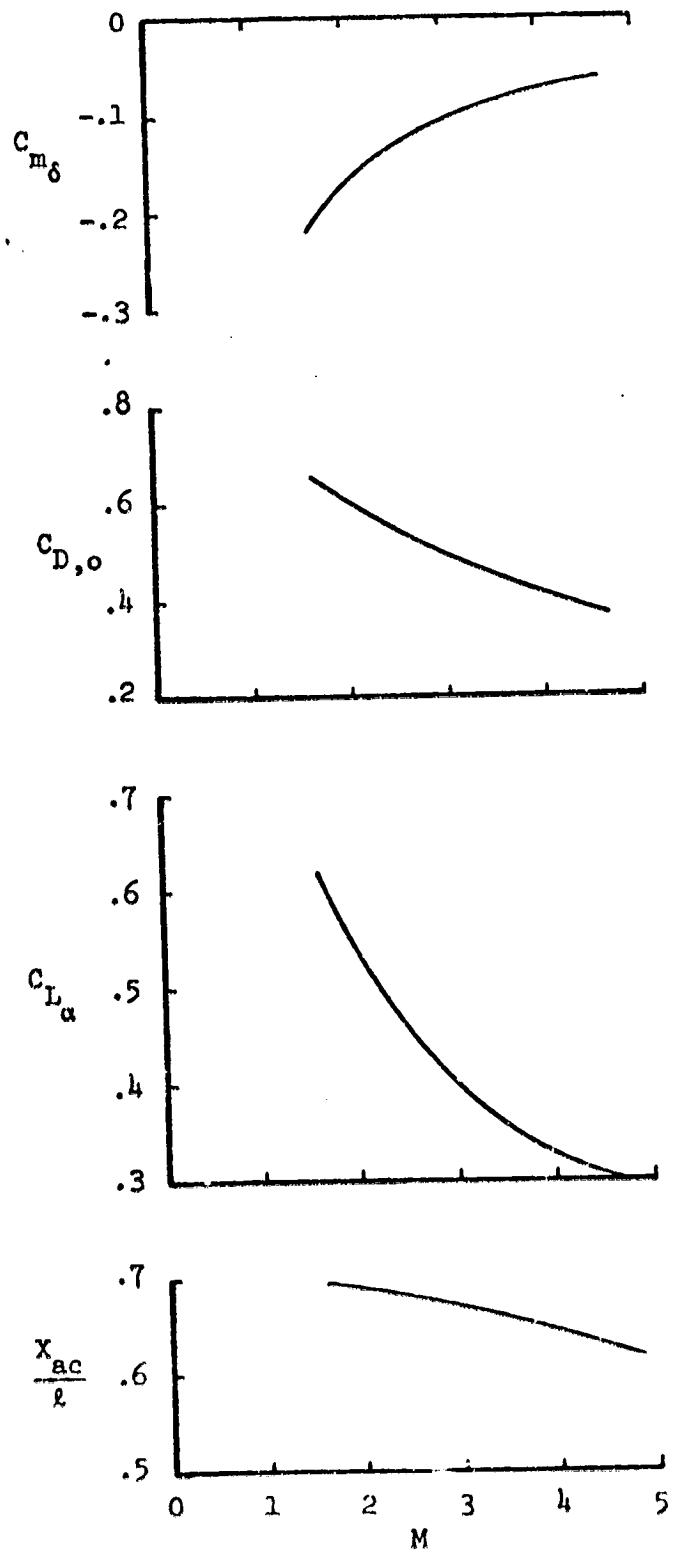
Variation of longitudinal parameters with Mach number; $\alpha \approx 0^\circ$.

SURFACE-TO-AIR MISSILE (SAM)



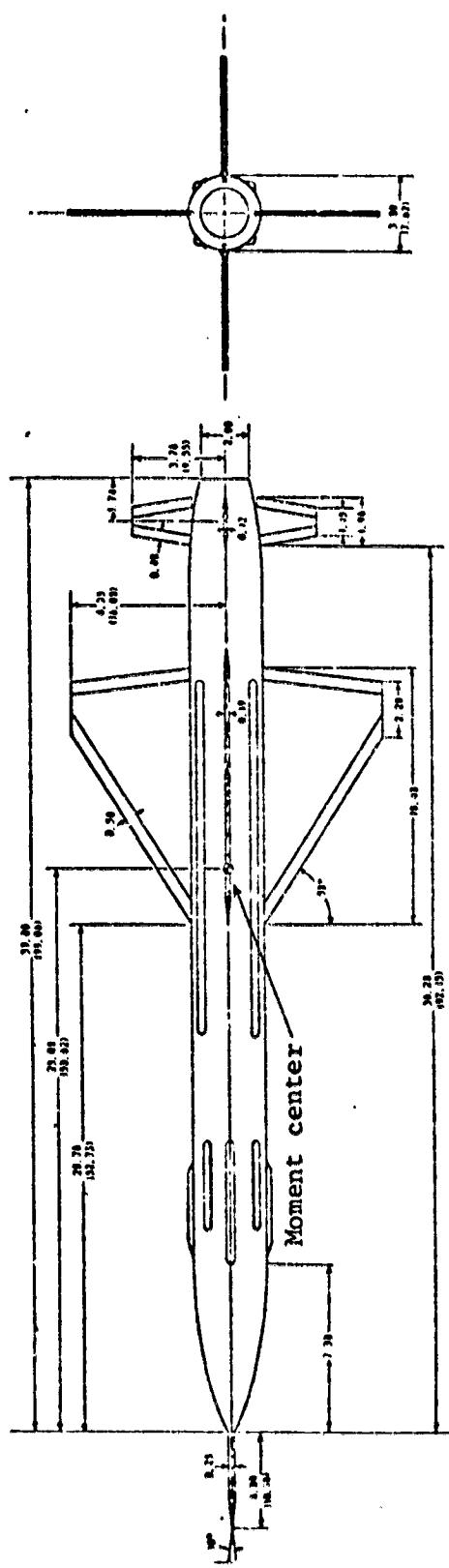
Details of model. (All linear dimensions are in inches.)

Ref. TM X-1025

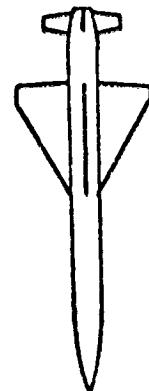
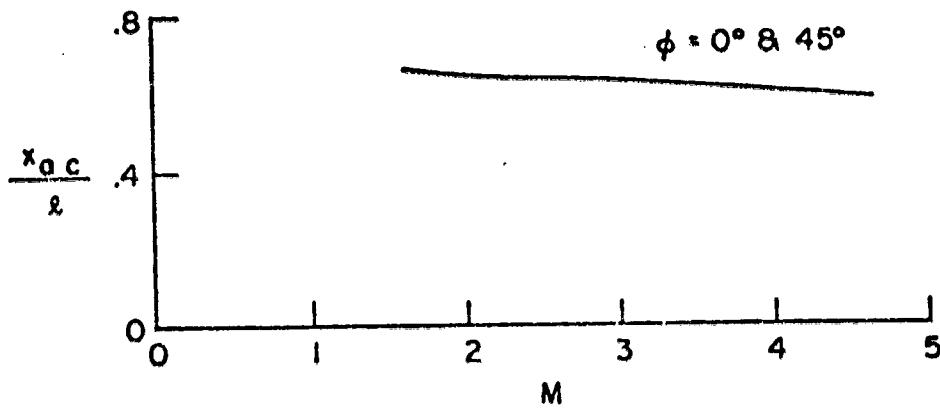
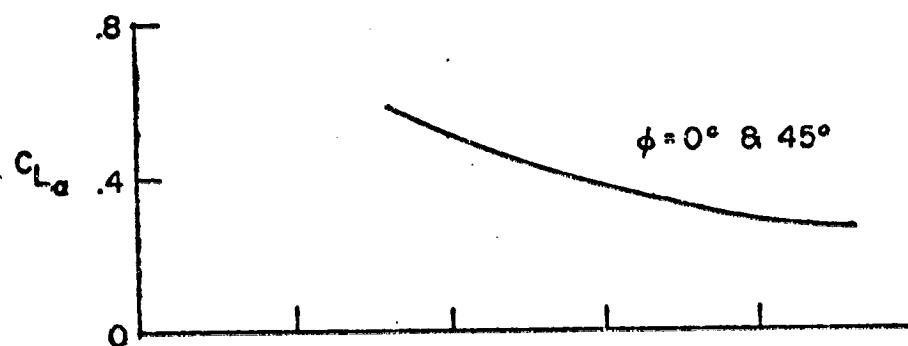
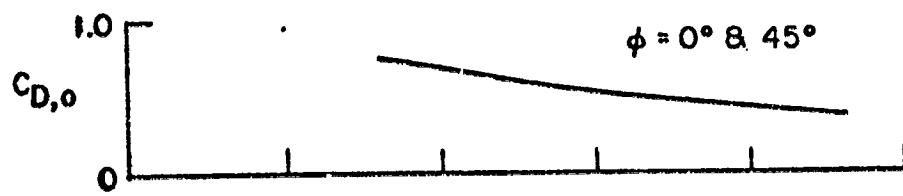
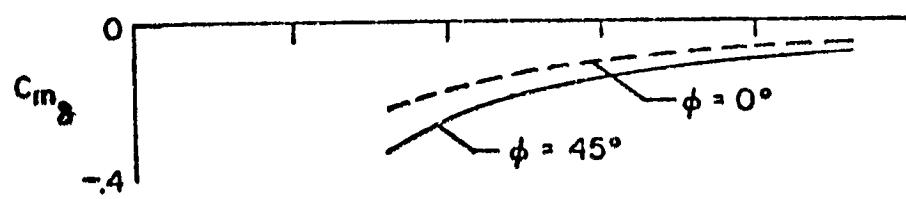


Variation of longitudinal parameters with Mach number; $\alpha=0$.

Ref. TM X-1025

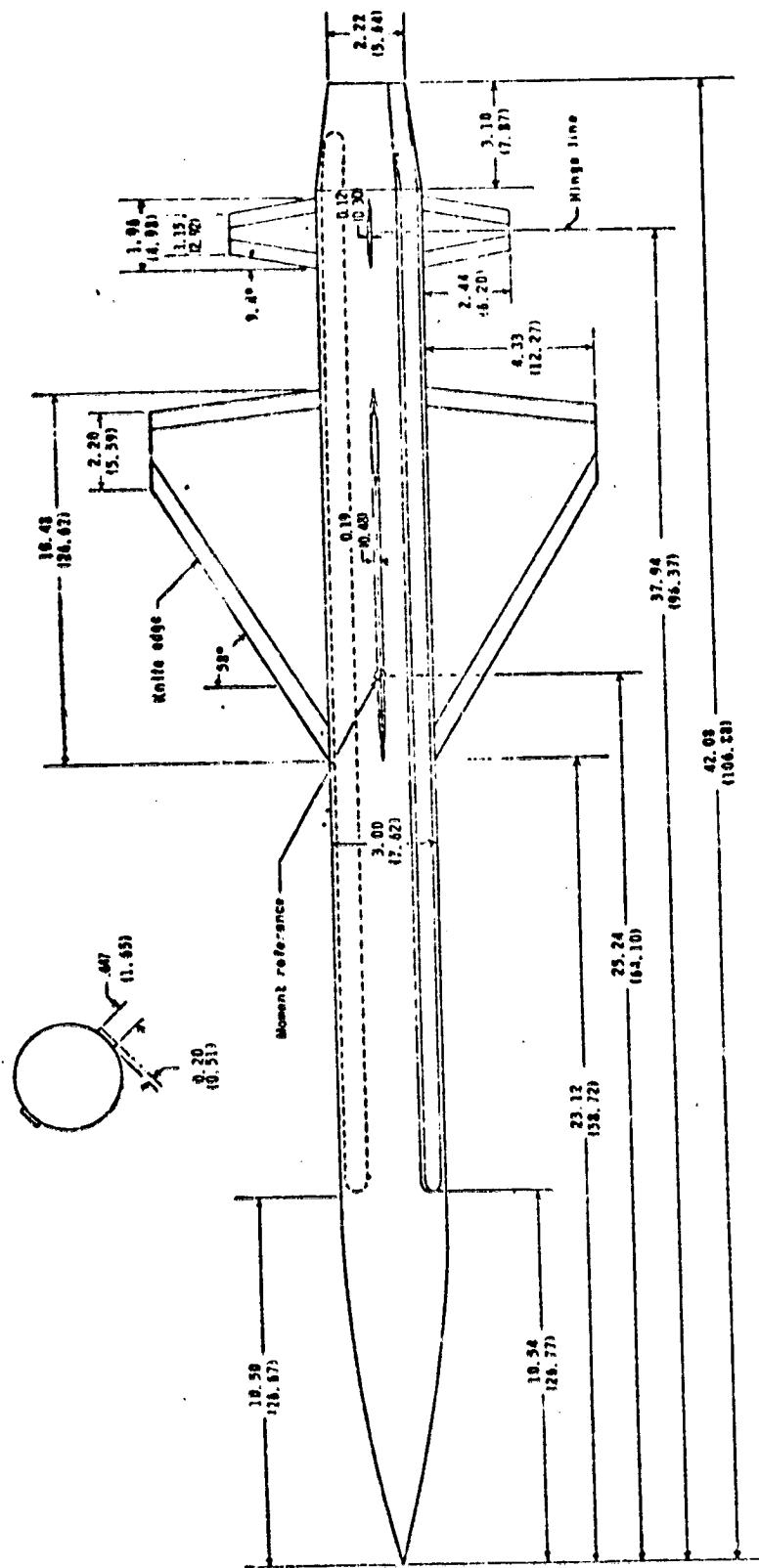


Details of model. [All linear dimensions are given in inches and parenthetically in centimeters. Because of space limitations, conversions to the International System of units are presented for only a few representative dimensions.]



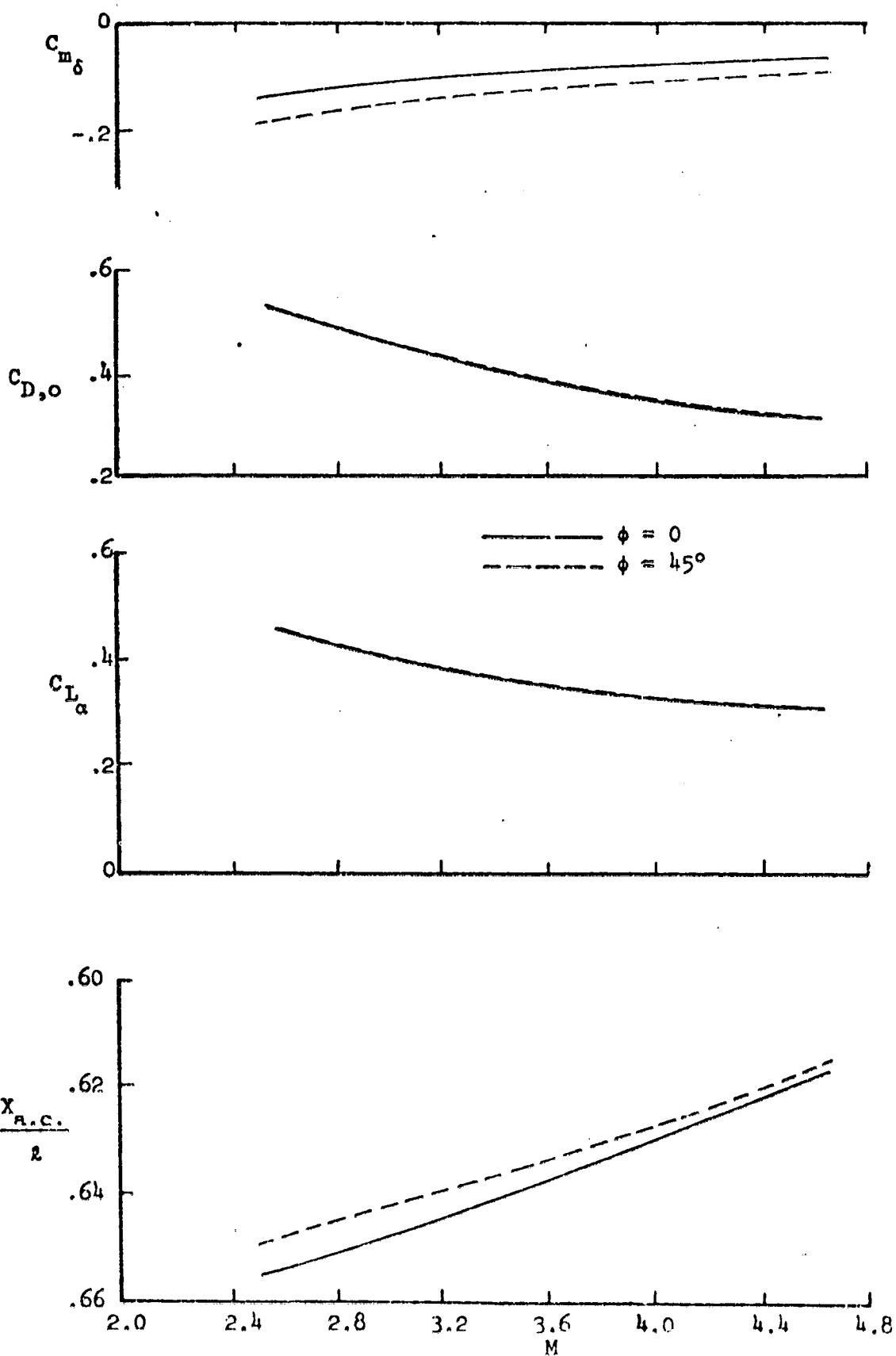
Variation of longitudinal parameters with Mach number; $\alpha=0$.

Ref. TM X-1416

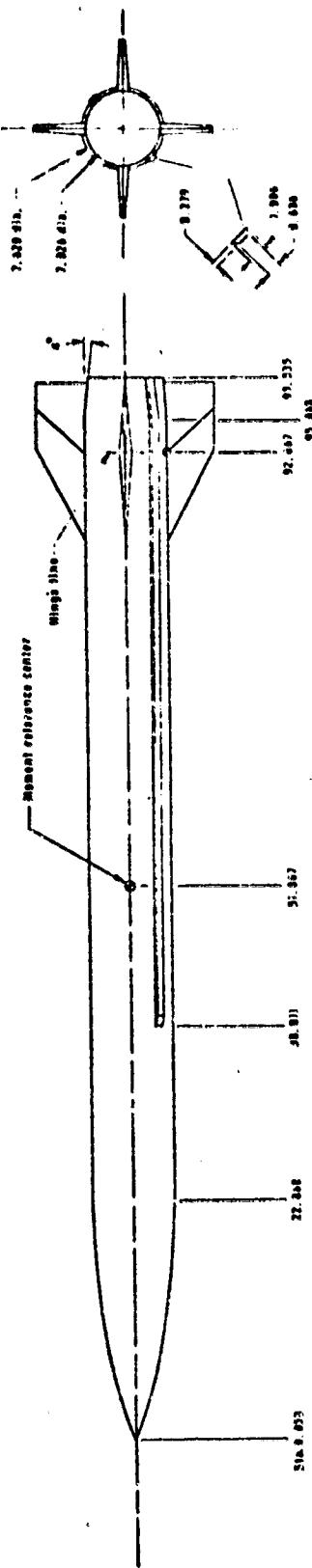


Model details. Dimensions are in inches and parenthetically in centimeters.

Ref. TM X-1751



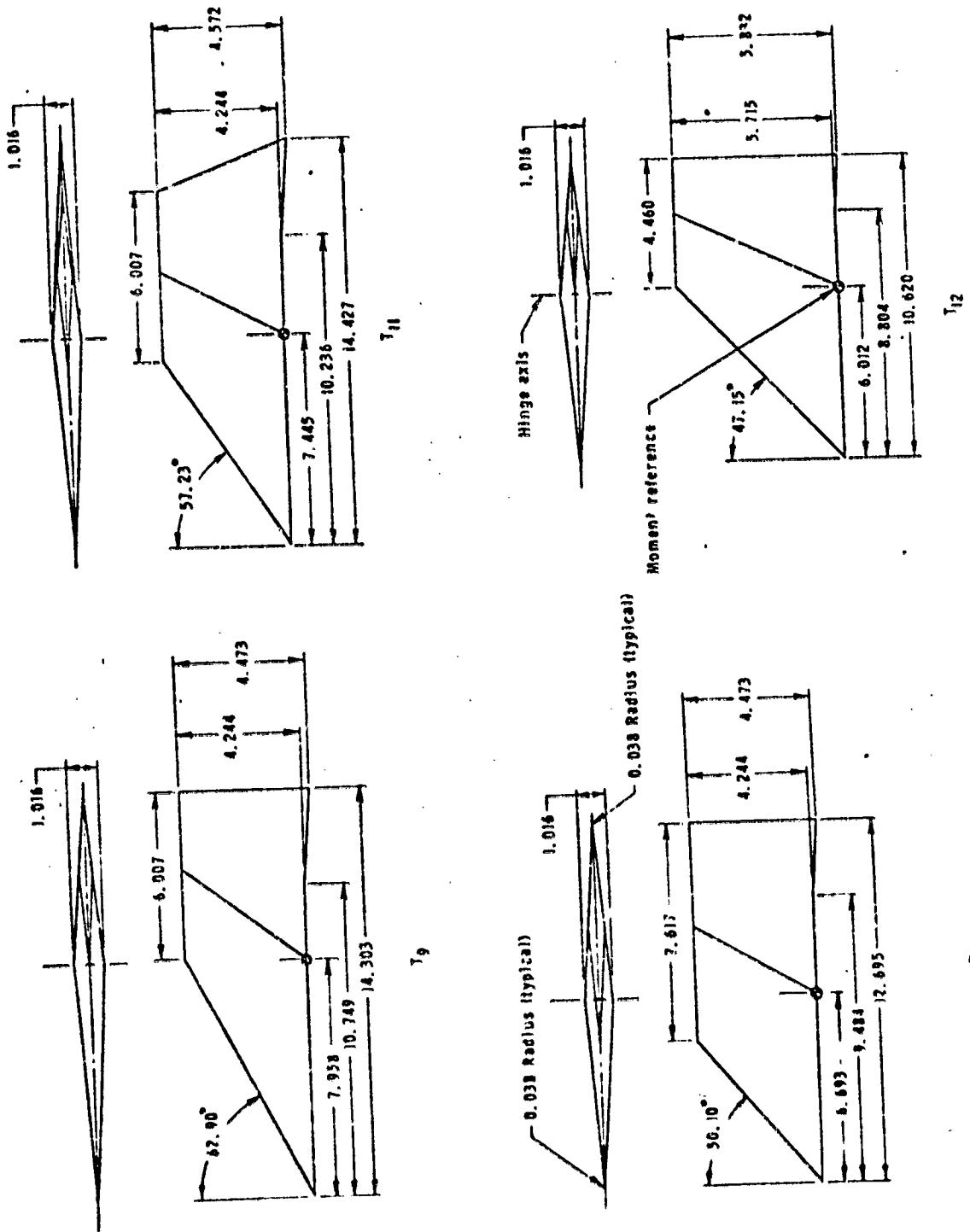
Variation of longitudinal parameters with Mach number; $\alpha=0$.



(a) Model details.

Drawing of model. All dimensions are in centimeters unless otherwise noted.

Ref. TM X-2774



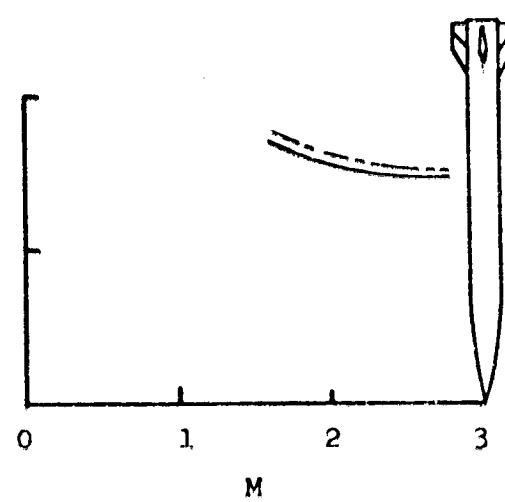
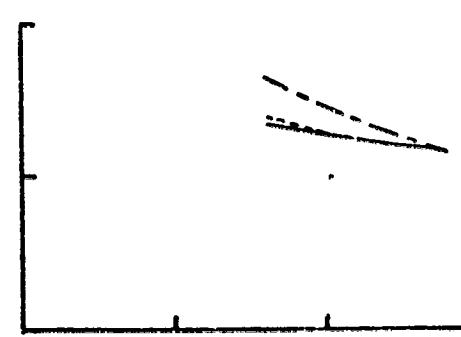
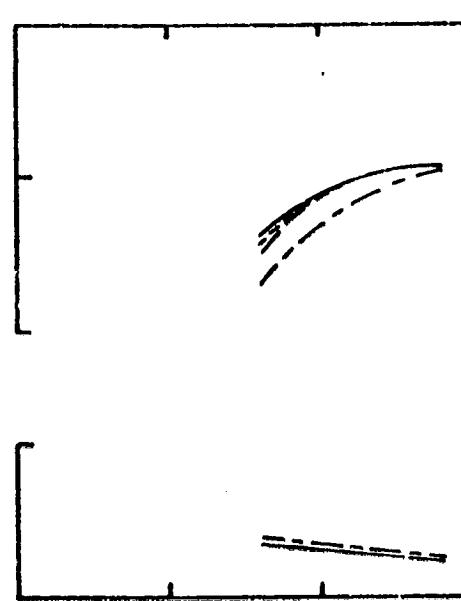
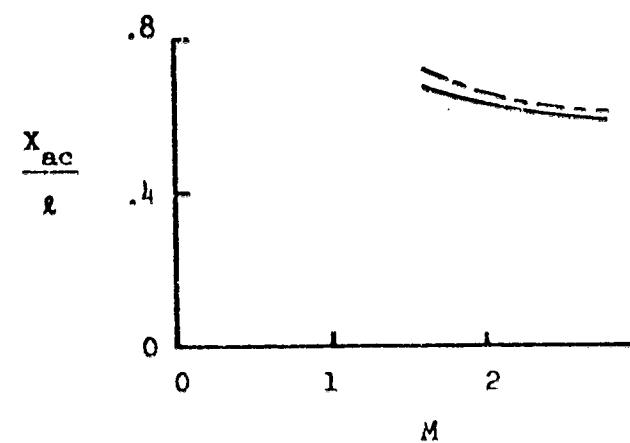
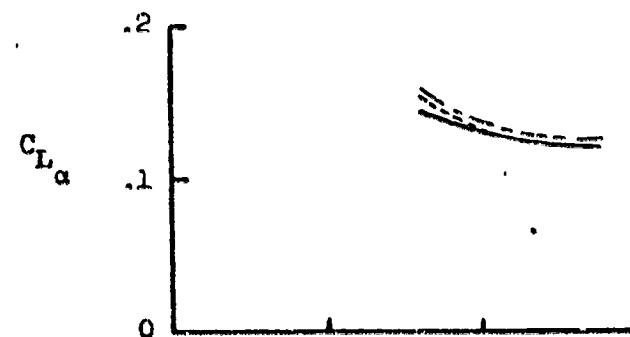
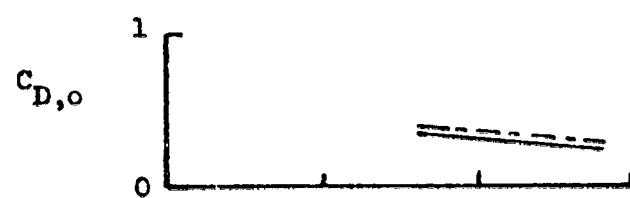
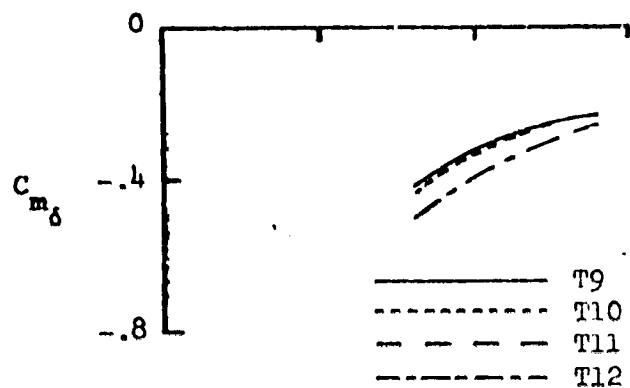
(b) Fin details.

Concluded.

Ref. TM X-2774

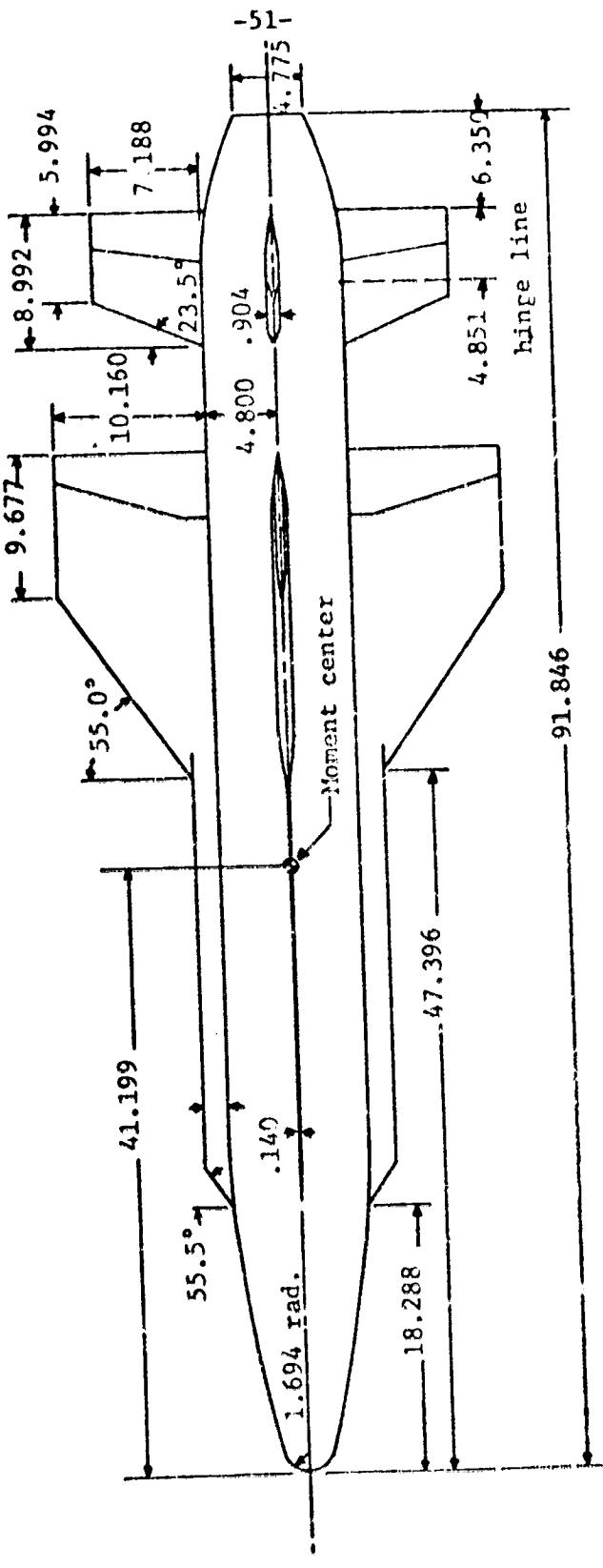
$\phi = 0^\circ$

$\phi = 45^\circ$



Variation of longitudinal parameters with Mach number; $\alpha=0$.

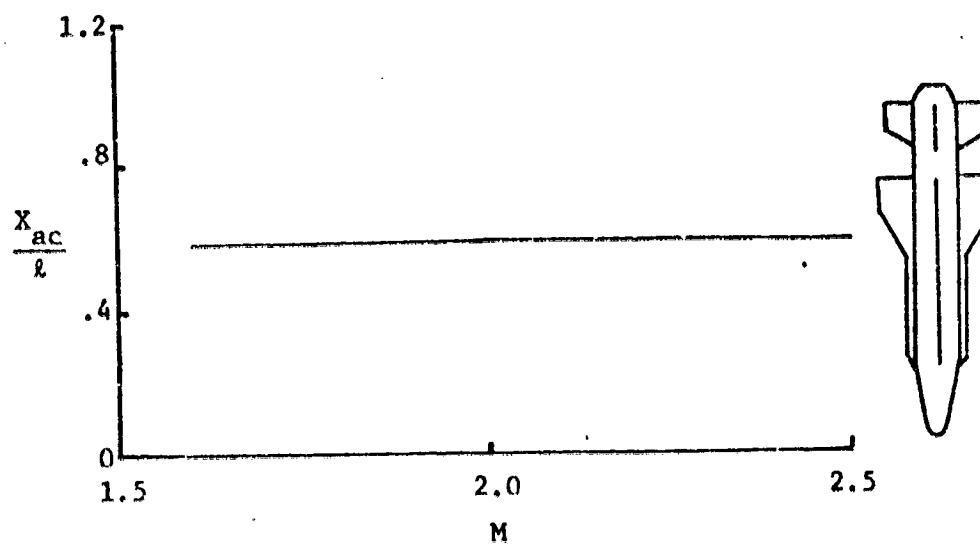
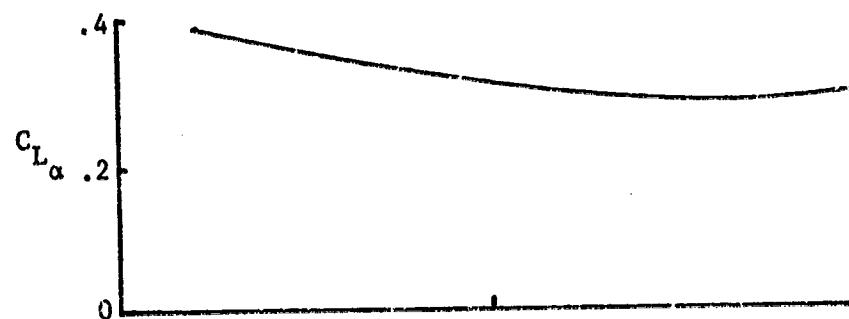
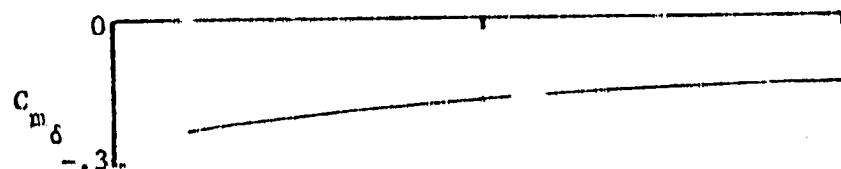
AIR-TO-SURFACE MISSILE (ASM)



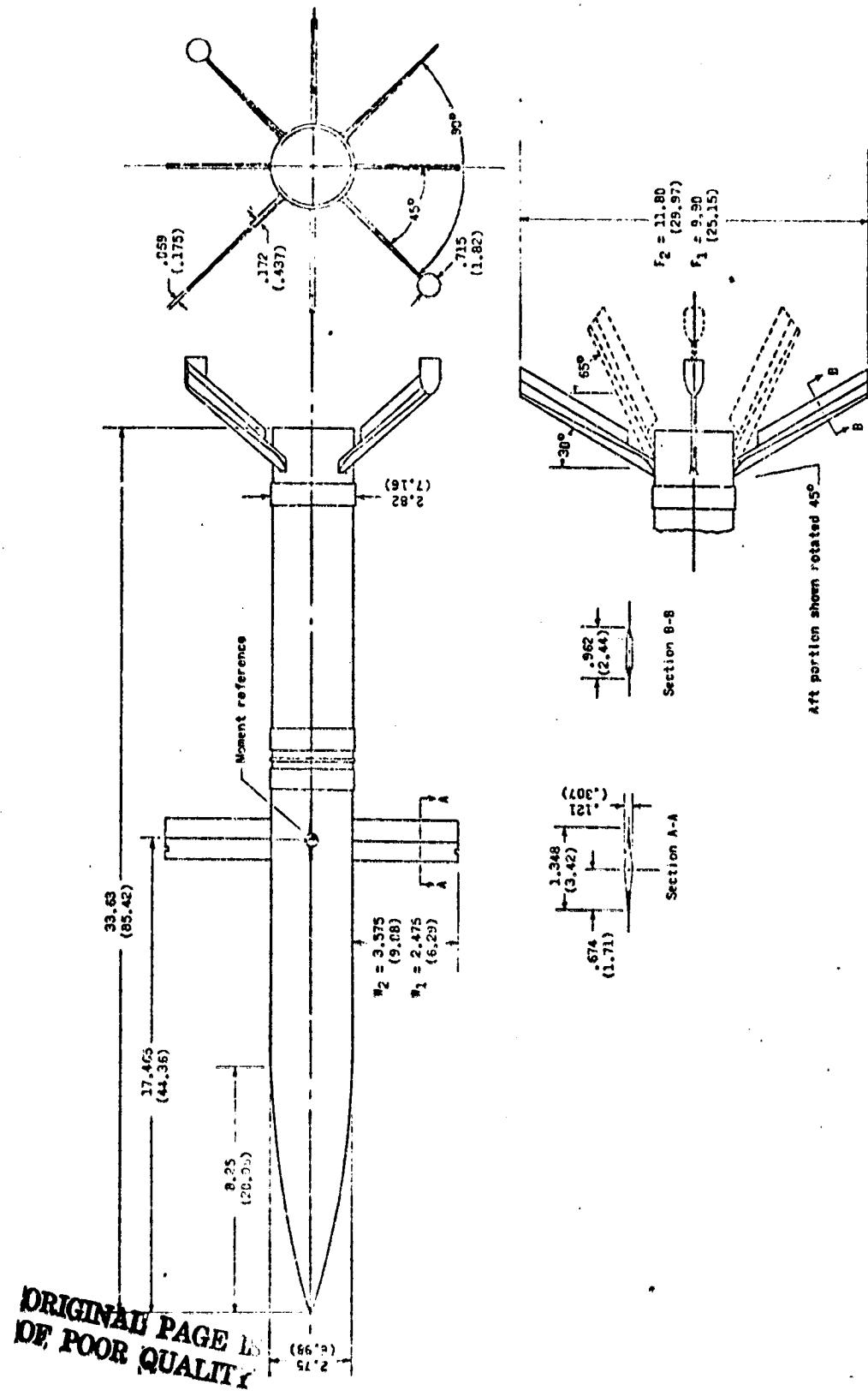
Model details. (All dimensions are in centimeters.)

Ref. TM X-1112

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Variation of longitudinal parameters with Mach number; $\alpha \approx 0^\circ$.



Details of the model. Dimensions are in inches (centimeters) unless otherwise noted.

Ref. TM X-1491

LONGITUDINAL PARAMETERS; $\alpha \approx 0^\circ$.

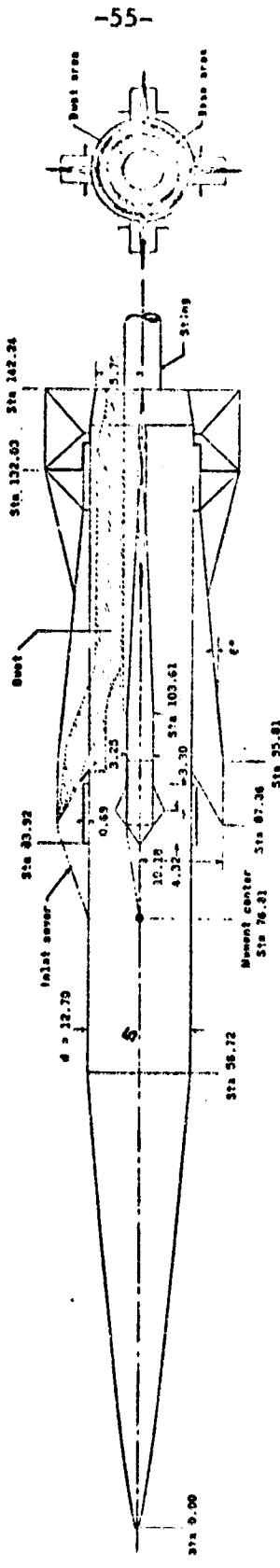
Mach Number 1.6

Config- uration	Fin Sweep	$C_{M\delta}$		$C_{D,o}$		$C_{L\alpha}$		X_{ac}/ℓ	
		$\phi=0^\circ$	$\phi=45^\circ$	$\phi=0^\circ$	$\phi=45^\circ$	$\phi=0^\circ$	$\phi=45^\circ$	$\phi=0^\circ$	$\phi=45^\circ$
BF ₁	65°	—	—	.380	—	.083	—	.617	.697
BF ₂	65°	—	—	.400	.398	.104	.108	.684	.697
BF ₂	30°	—	—	.565	.560	.114	.114	.702	.720
BF _{2W2}	30°	-.012	-.016	.688	.690	.218	.227	.619	.619
BF _{1W1}	30°	-.012	-.016	.610	.590	.174	.185	.606	.603

Mach Number 2.0

Config- uration	Fin Sweep	$C_{M\delta}$		$C_{D,o}$		$C_{L\alpha}$		X_{ac}/ℓ	
		$\phi=0^\circ$	$\phi=45^\circ$	$\phi=0^\circ$	$\phi=45^\circ$	$\phi=0^\circ$	$\phi=45^\circ$	$\phi=0^\circ$	$\phi=45^\circ$
BF ₁	65°	—	—	.36	.368	.075	.083	.581	.549
BF ₂	65°	—	—	.38	.38	.100	.107	.630	.622
BF ₂	30°	—	—	.508	.509	.110	.106	.683	.694
BF _{2W2}	30°	0	.01	.628	.628	.194	.239	.609	.612
BF _{1W1}	30°	-.012	0	.542	.54	.161	.156	.590	.598

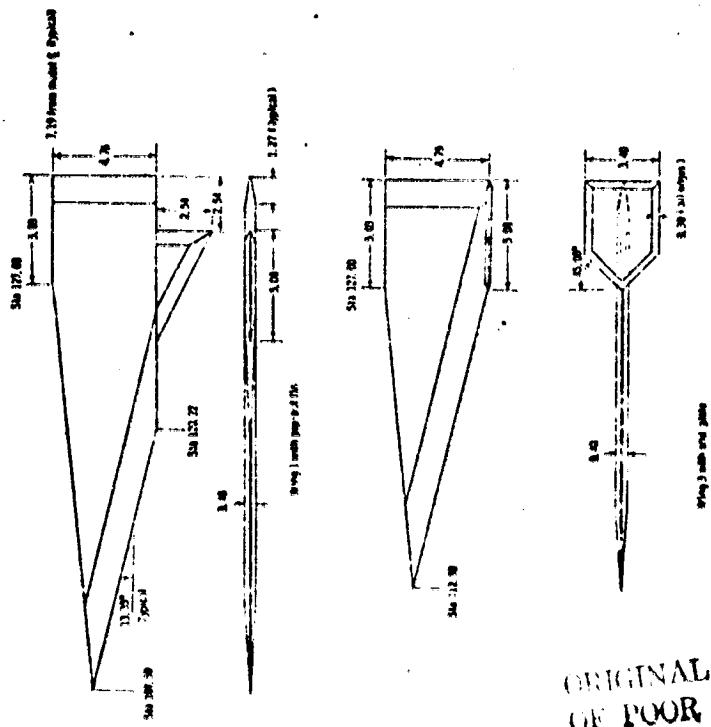
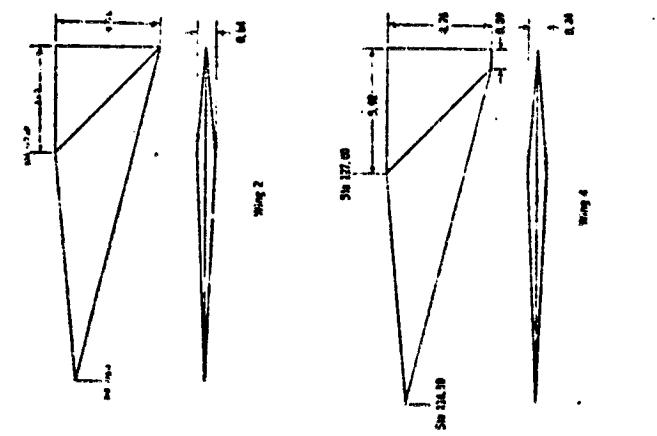
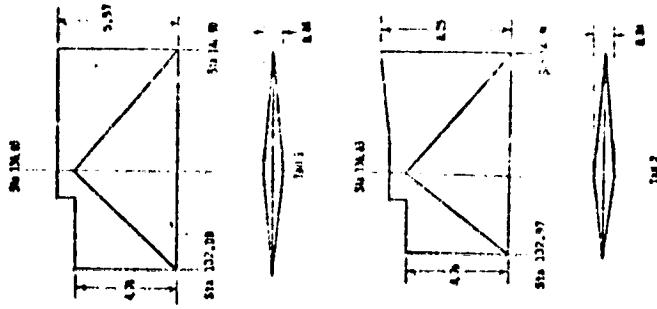
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(a) Basic model W2T1.

Model details. (All linear dimensions are in centimeters.)

Ref. TM X-1492



(b) Wings and tails.
Continued.

Ref: TM X-1492

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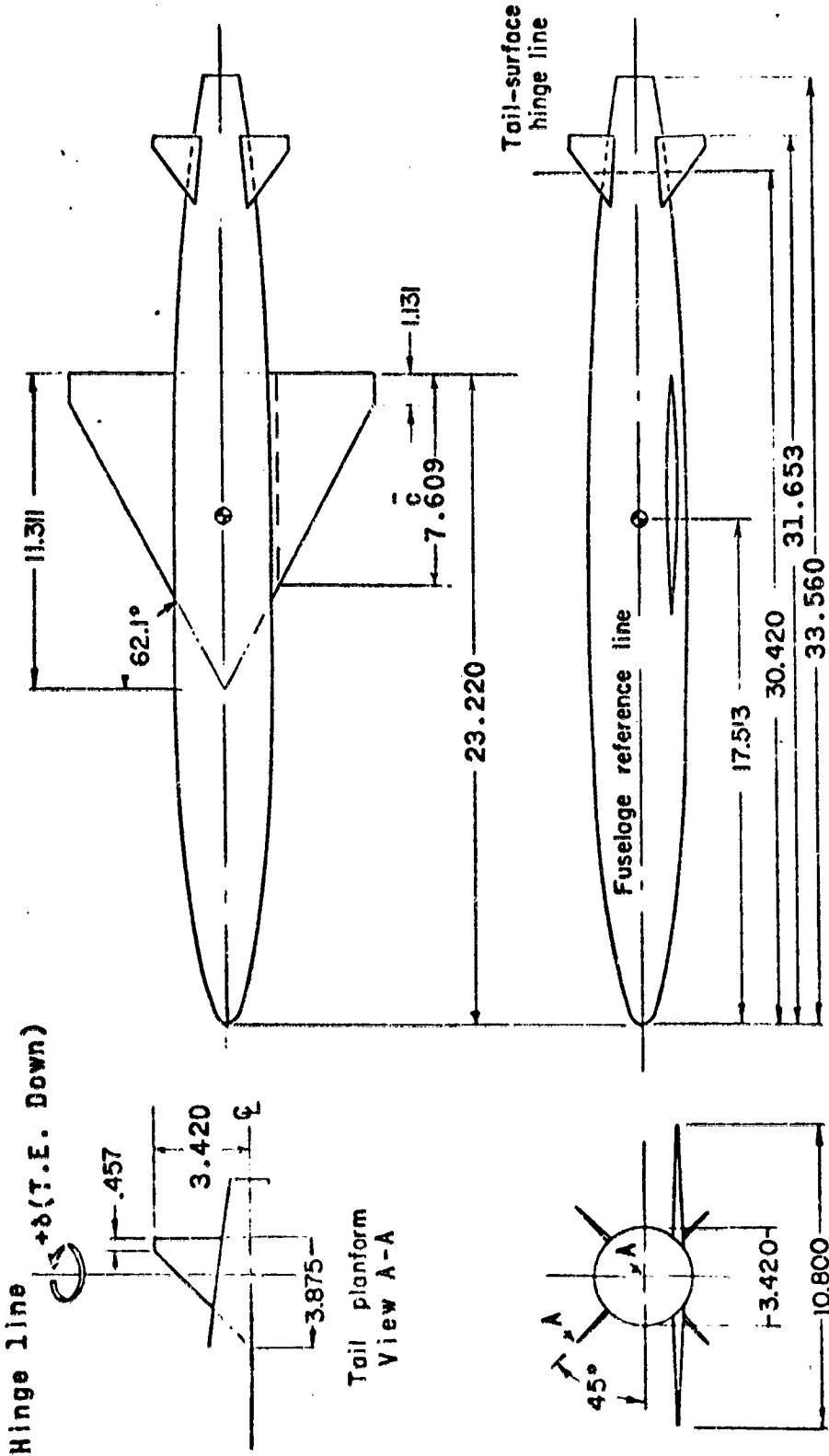
LONGITUDINAL PARAMETERS AT MACH NUMBER 2.5, WITH INLETS COVERED; $\alpha=0^\circ$.

$\phi = 0^\circ$

CONFIGURATION	C_{m_δ}	$C_{D,o}$	C_{L_α}	$\frac{x_{ac}}{L}$
Wing 1, Tail 1	-0.0829	0.247	0.155	0.611
Wing 1, Tail 1, Pop-out Fin	-0.0859	0.255	0.159	0.628
Wing 2, Tail 1	-0.0933	0.245	0.124	0.581
Wing 3, Tail 1	-0.0773	0.242	0.125	0.602
Wing 3, Tail 1, End Plate	-0.0762	0.255	0.148	0.622
Wing 4, Tail 2	-0.0821	0.240	0.129	0.574

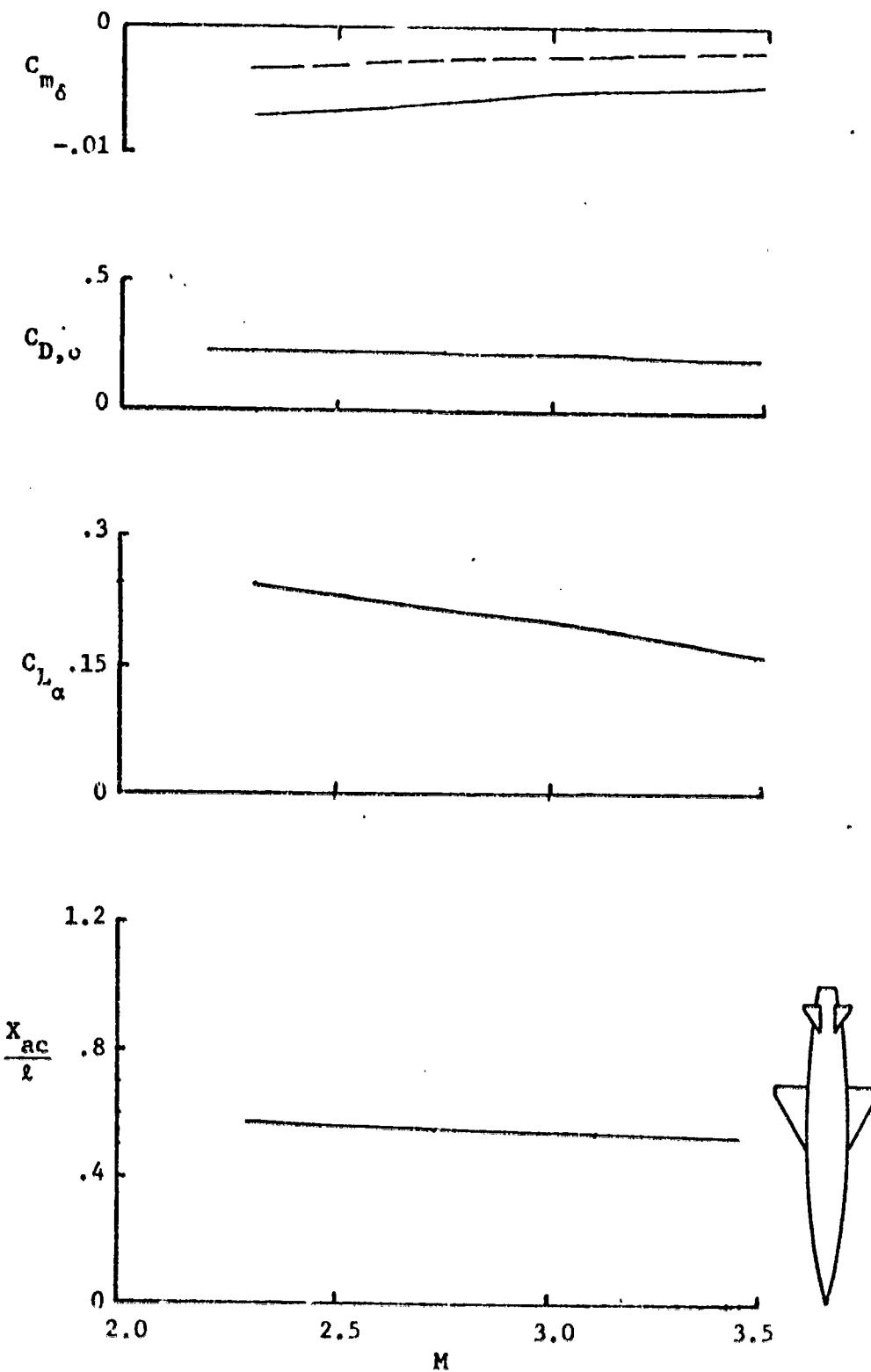
$\phi = 45^\circ$

CONFIGURATION	C_{m_δ}	$C_{D,o}$	C_{L_α}	$\frac{x_{ac}}{L}$
Wing 1, Tail 1	-0.1176	0.250	0.146	0.603
Wing 1, Tail 1, Pop-out Fin	-0.1165	0.257	0.154	0.624
Wing 2, Tail 1	-0.1262	0.247	0.122	0.574
Wing 3, Tail 1	-0.1198	0.247	0.135	0.584
Wing 3, Tail 1, End Plate	-0.1142	0.256	0.150	0.614
Wing 4, Tail 2	-0.1128	0.243	0.128	0.563



Details of a low-wing missile with interdigitated tail surfaces. All dimensions are in inches unless otherwise noted.

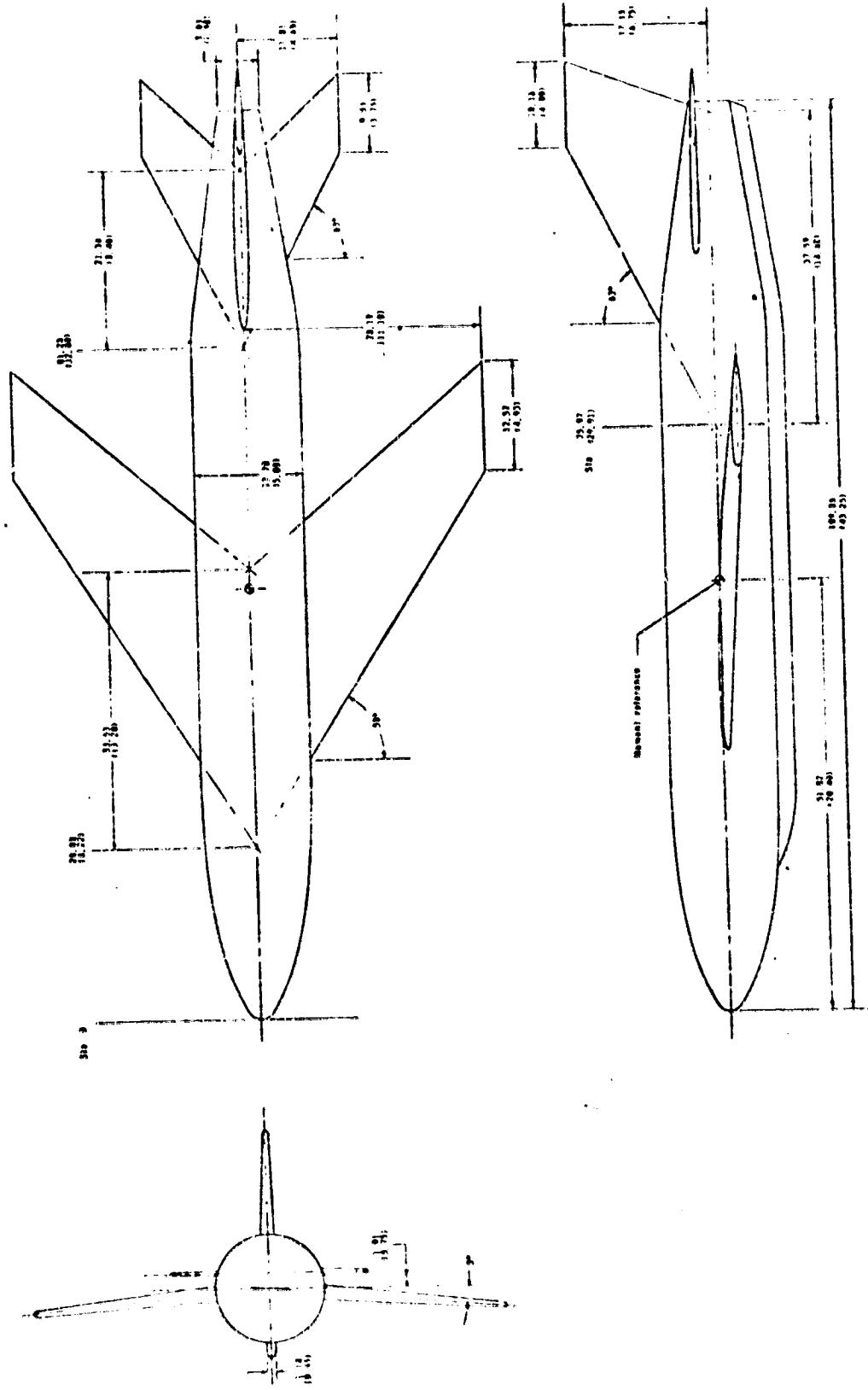
Ref. RM L58C19



Variation of longitudinal parameters with Mach number; $\alpha=3^\circ$.

Ref. RM 158C19

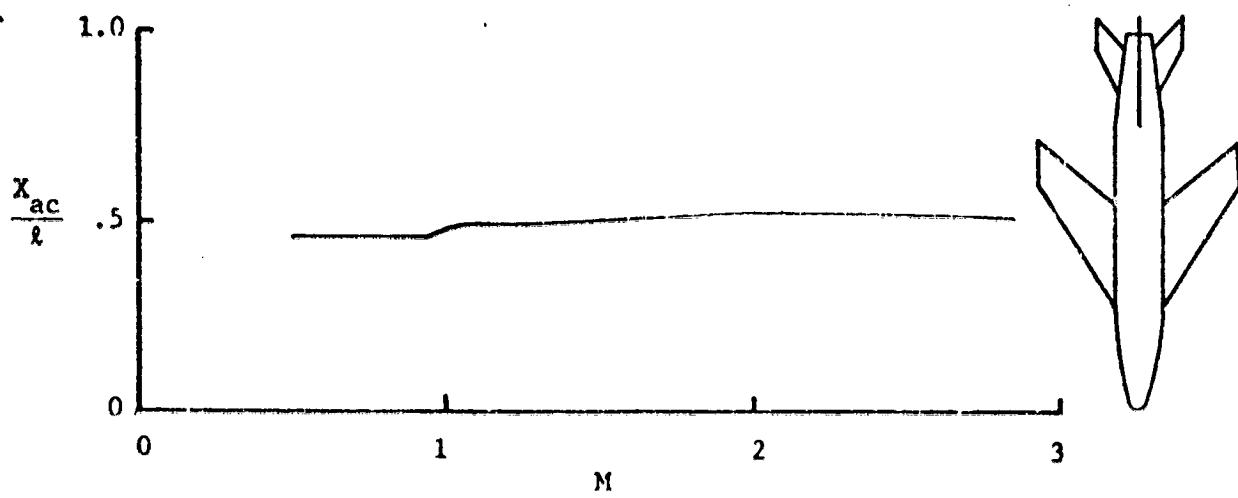
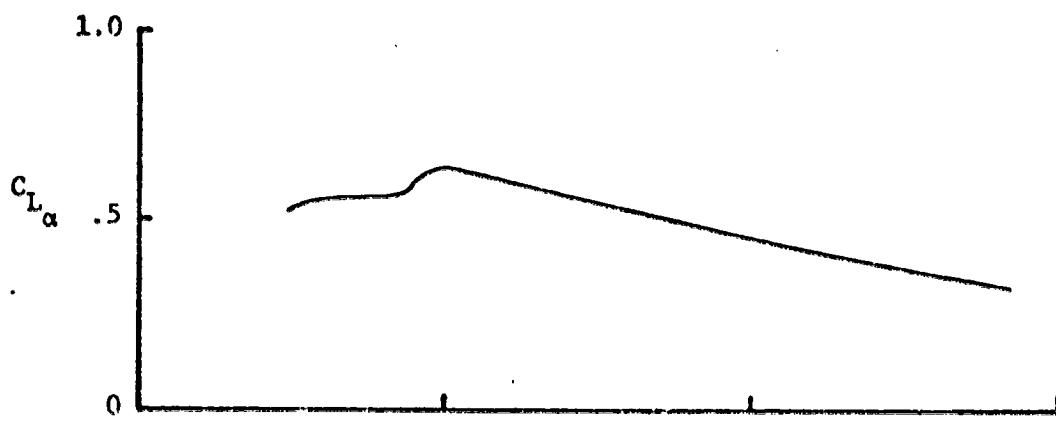
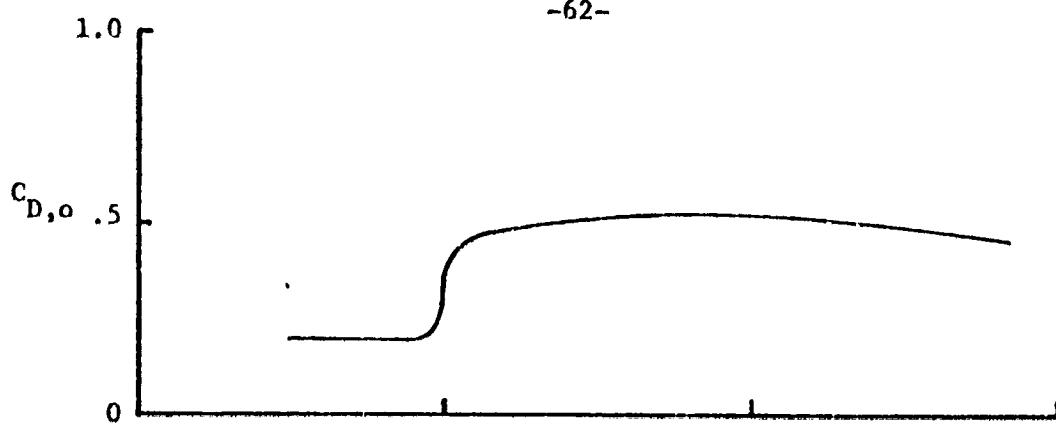
CRUISE, TARGET DRONE



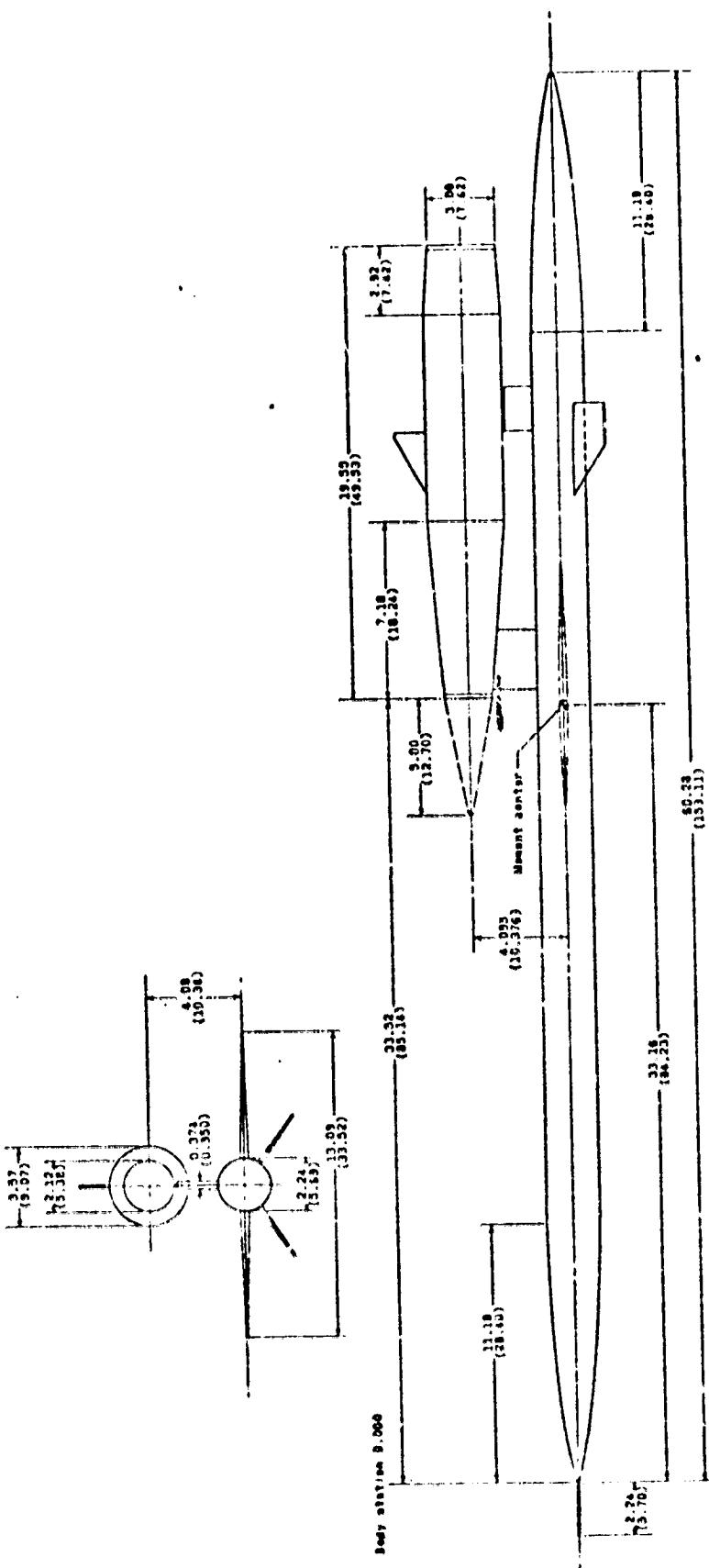
Details of model. Linear dimensions are in centimeters (inches).

Ref. TN D-7069

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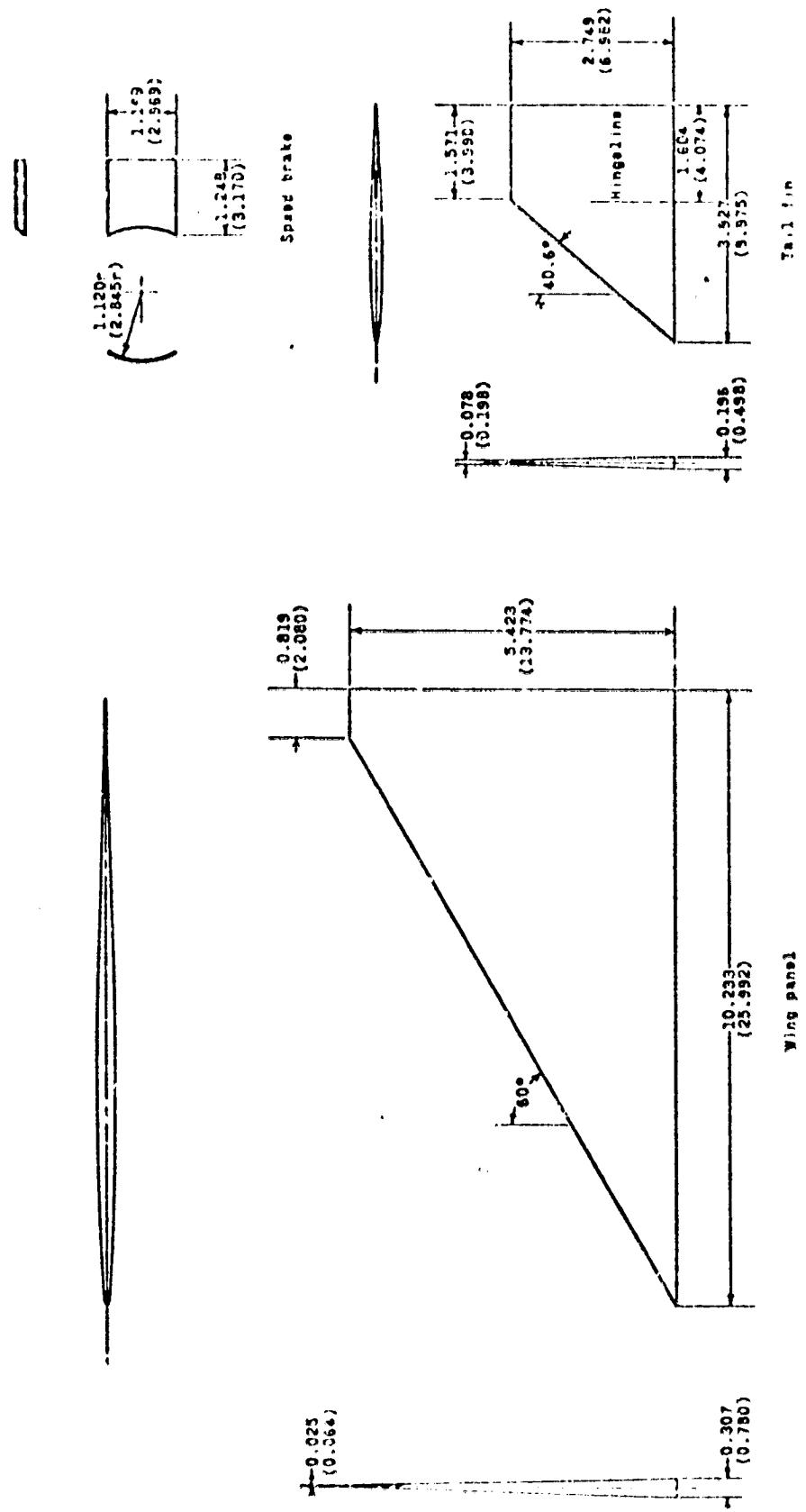


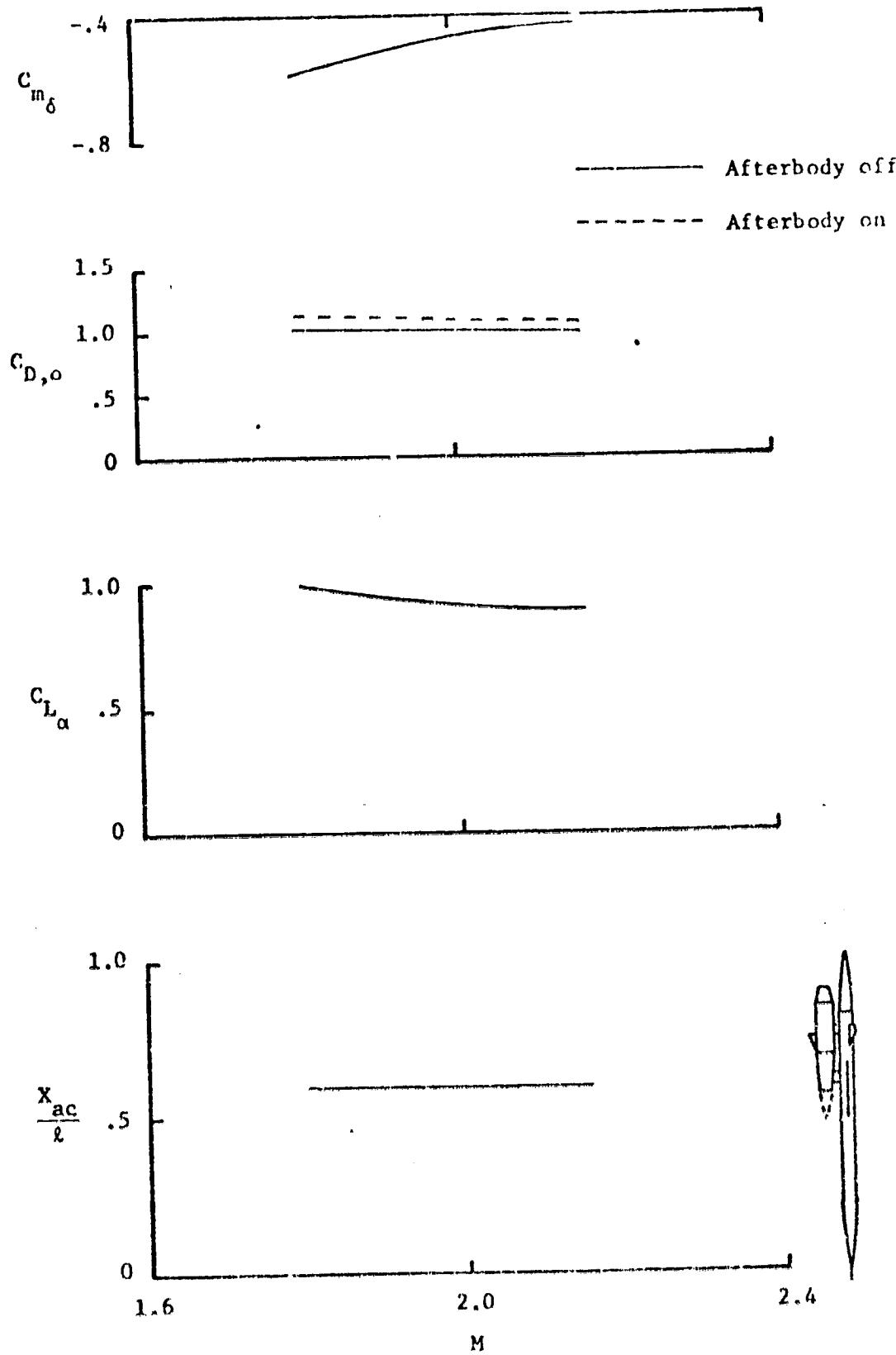
Variation of longitudinal parameters with Mach number; $\alpha=0^\circ$.



Model details. (All dimensions are given in inches and parenthetically in centimeters.)

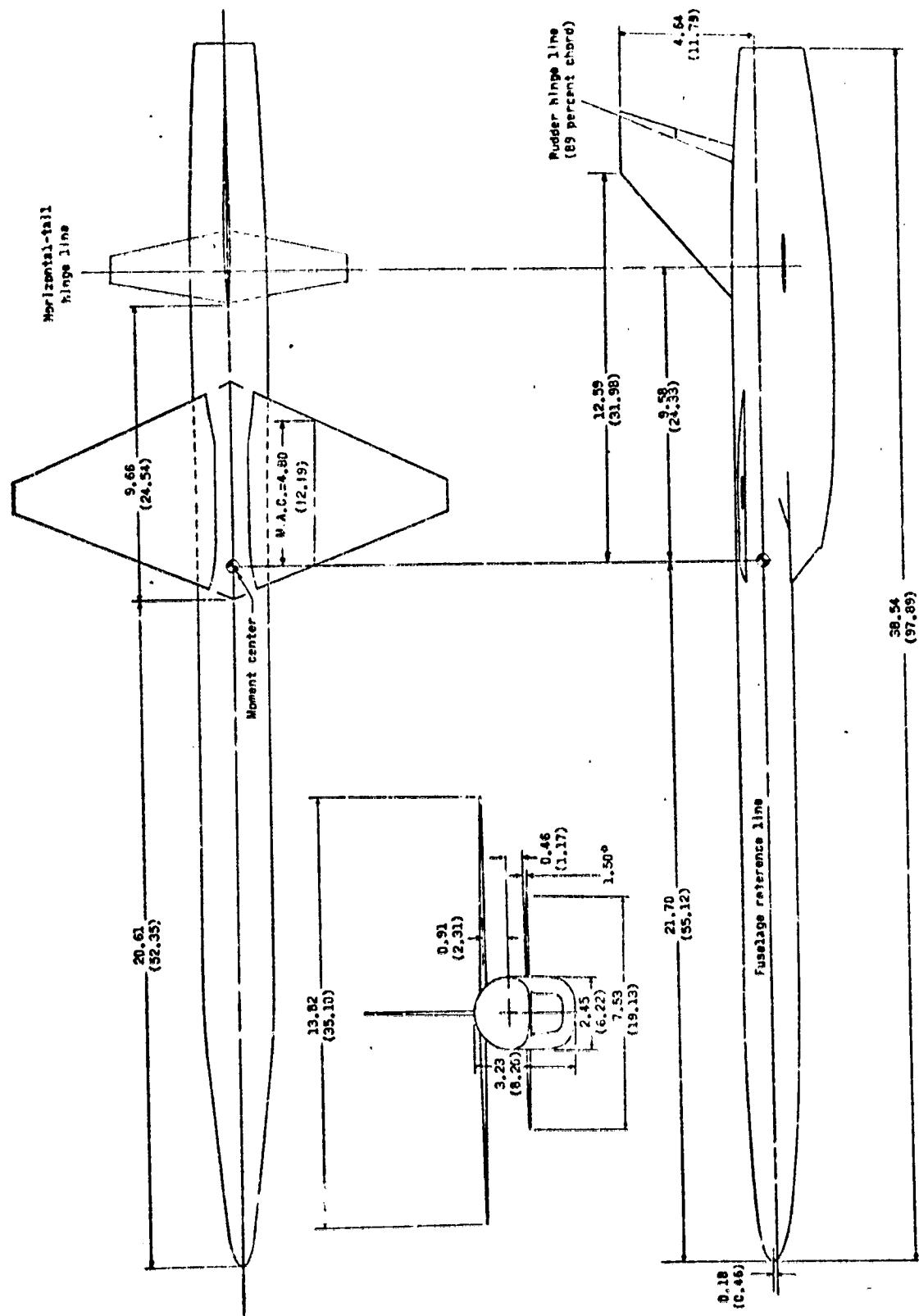
Ref. TM X-1304





Variation of longitudinal parameters with Mach number; $\alpha = 0^\circ$.

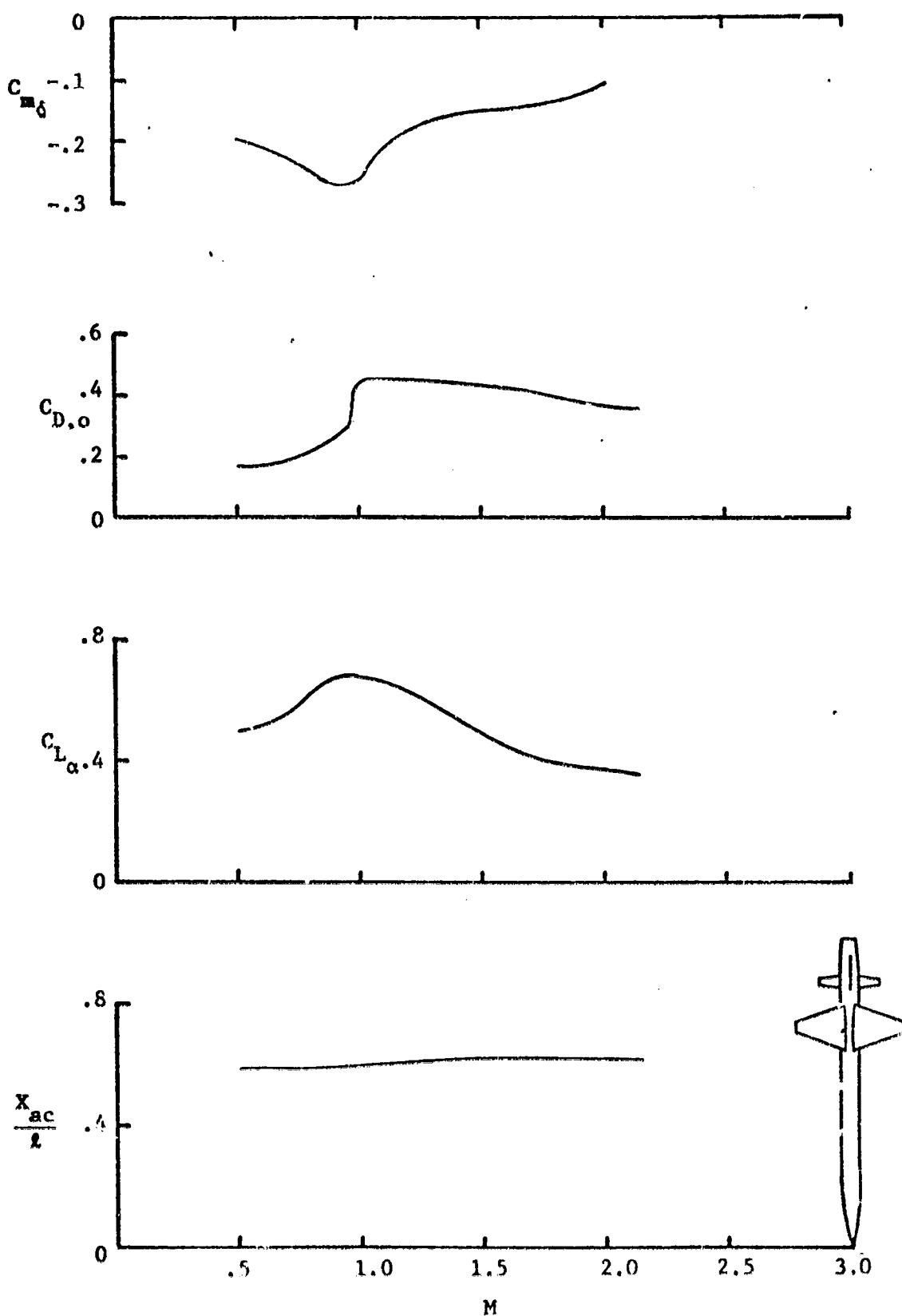
Ref. TM X-1304



Three-view drawing of the model. Dimensions are given in inches and parenthetically in centimeters.

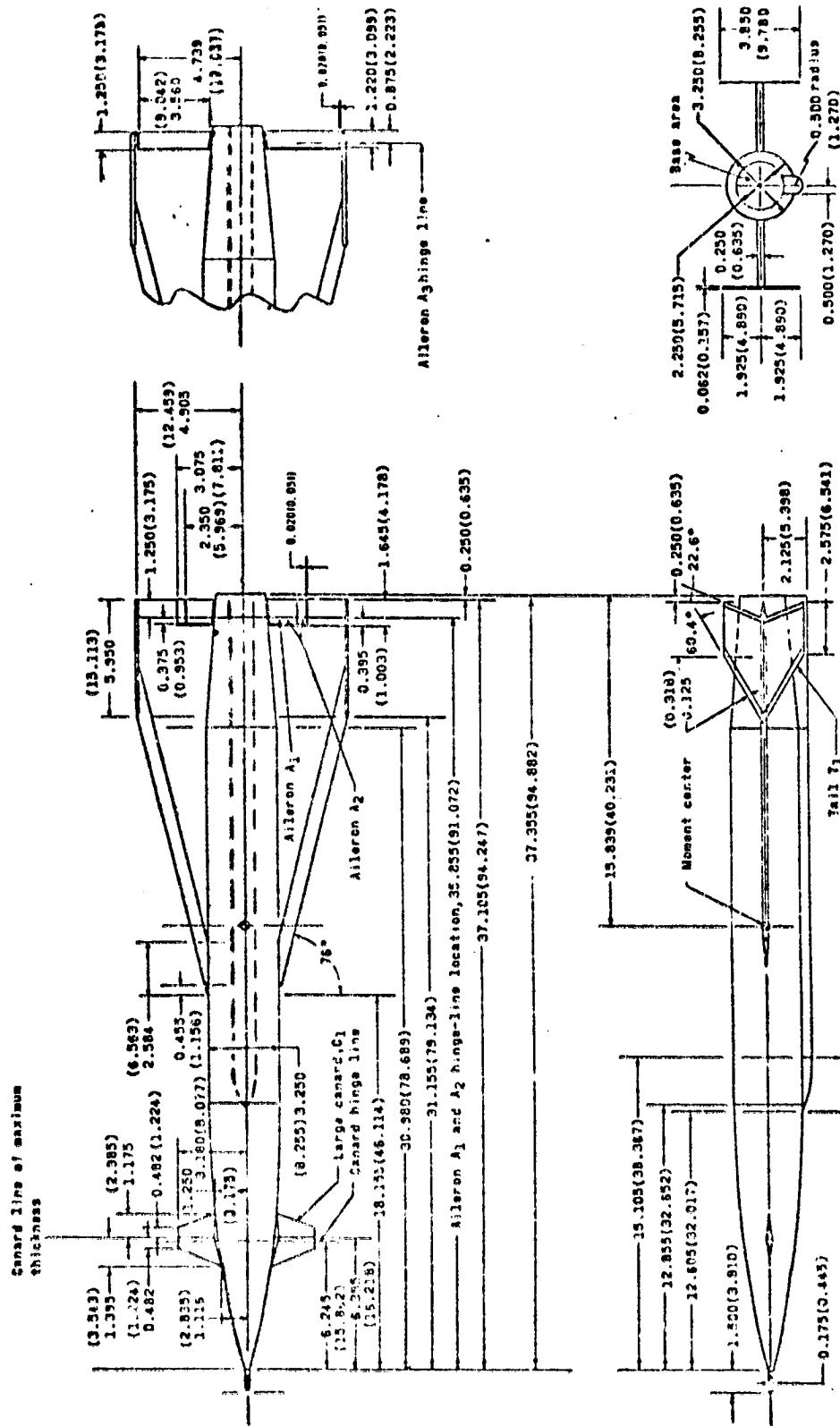
Ref. TM X-1538

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Variation of longitudinal parameters with Mach number,
configuration PW HV; $\alpha = 0^\circ$.

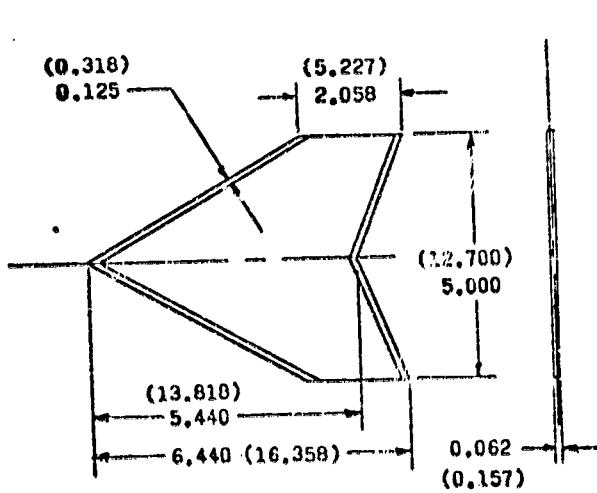
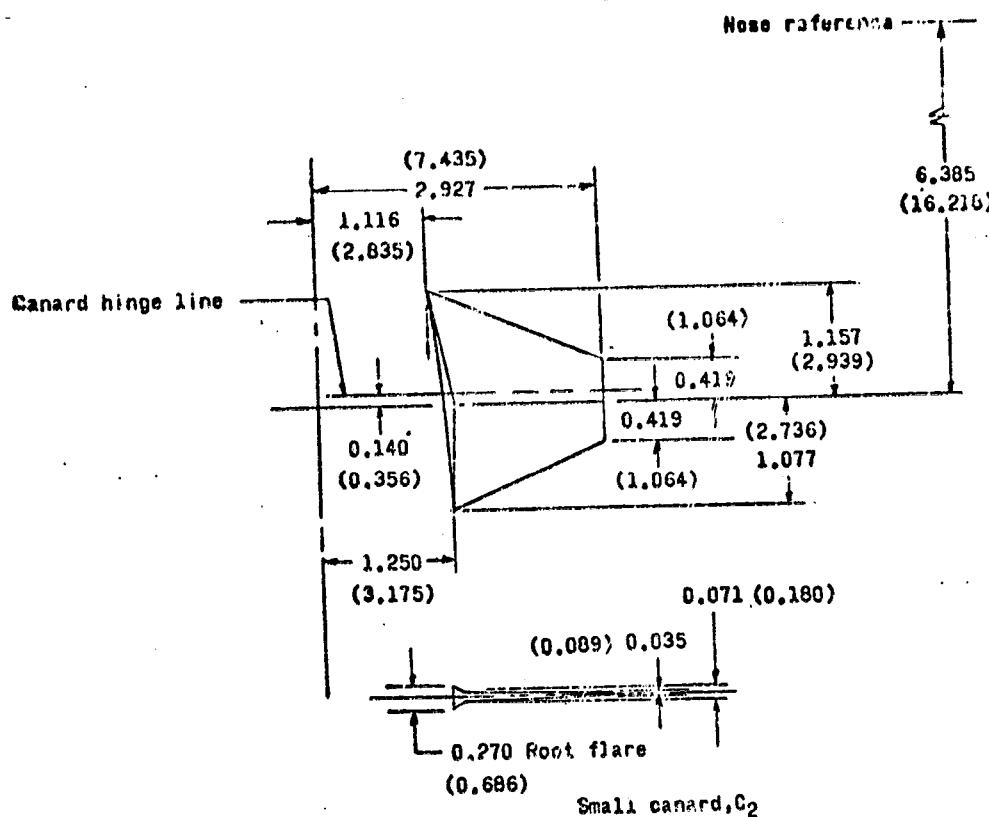
Ref. TM X-1538



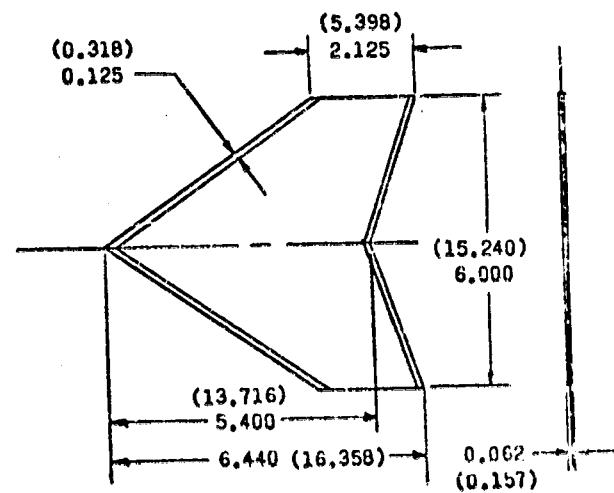
Details of model. All dimensions are given first in inches and parenthetically in centimeters.

Ref. TM SX-1531

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Tail T₂



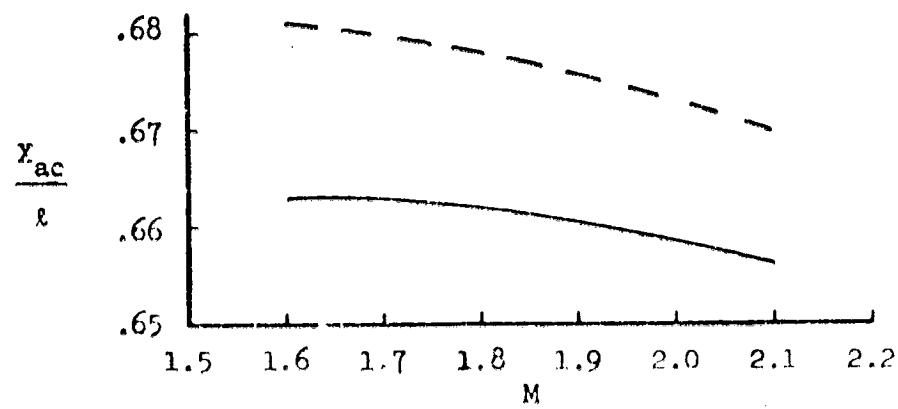
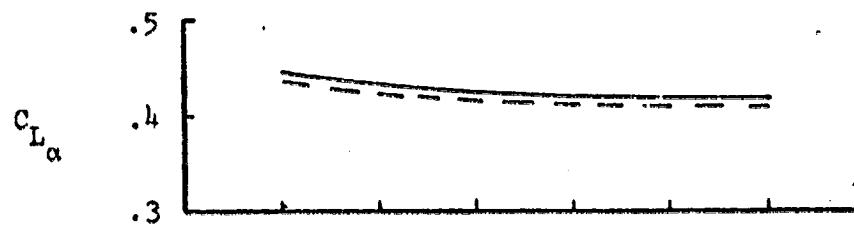
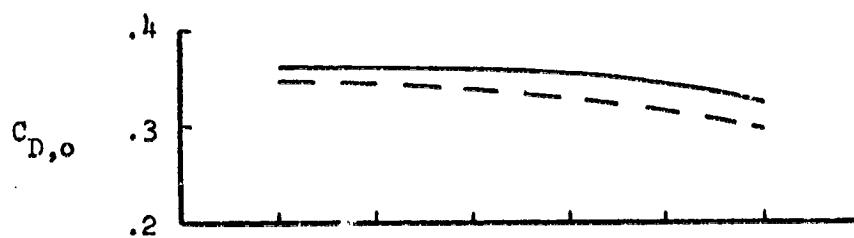
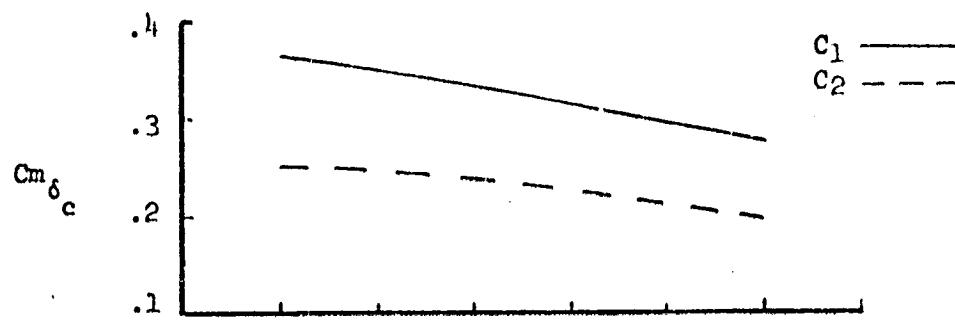
Tail T₃

(b) Vertical tails and canard.

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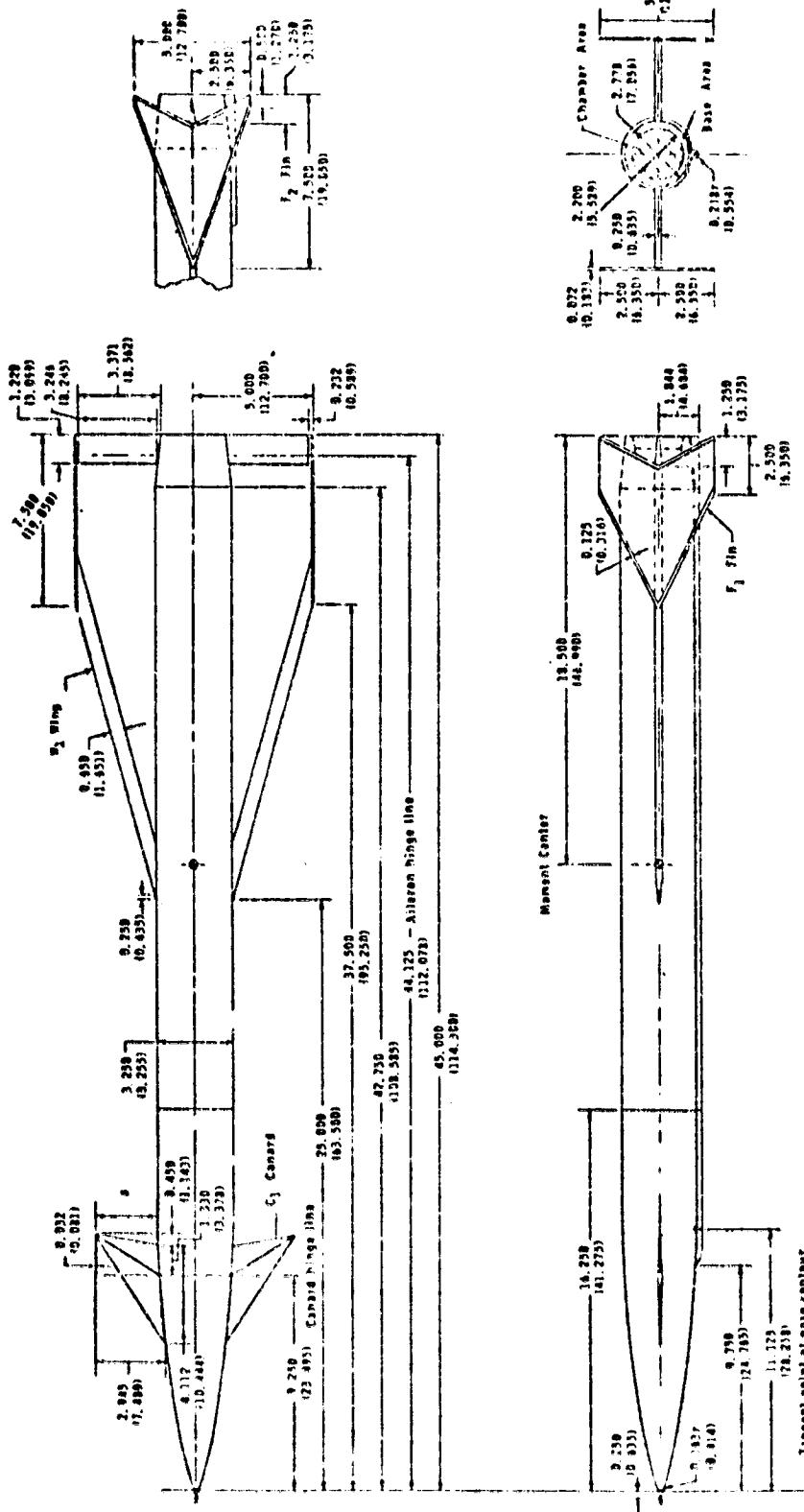
Ref. TM SX-1531

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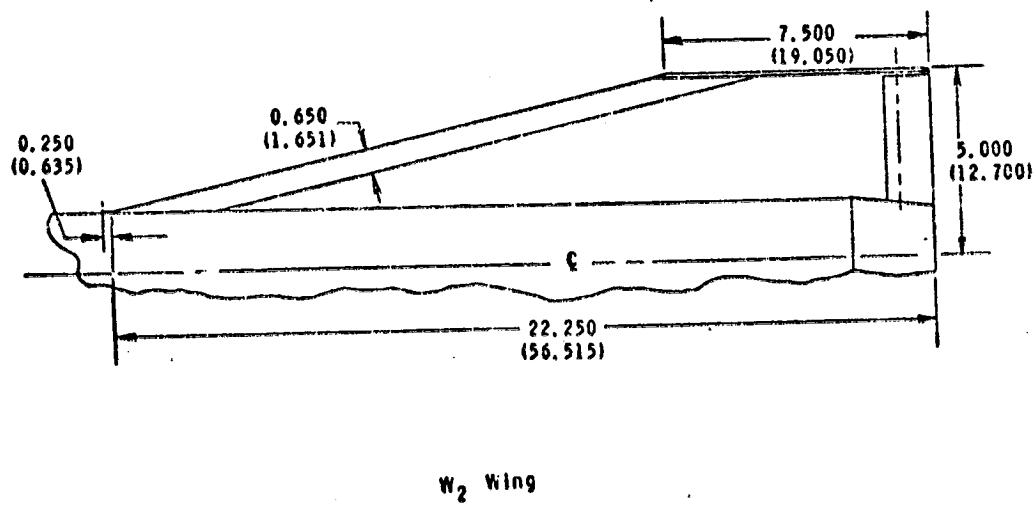
Variation of longitudinal parameters with Mach number; $\alpha=0$.

Ref. TM SX-1531



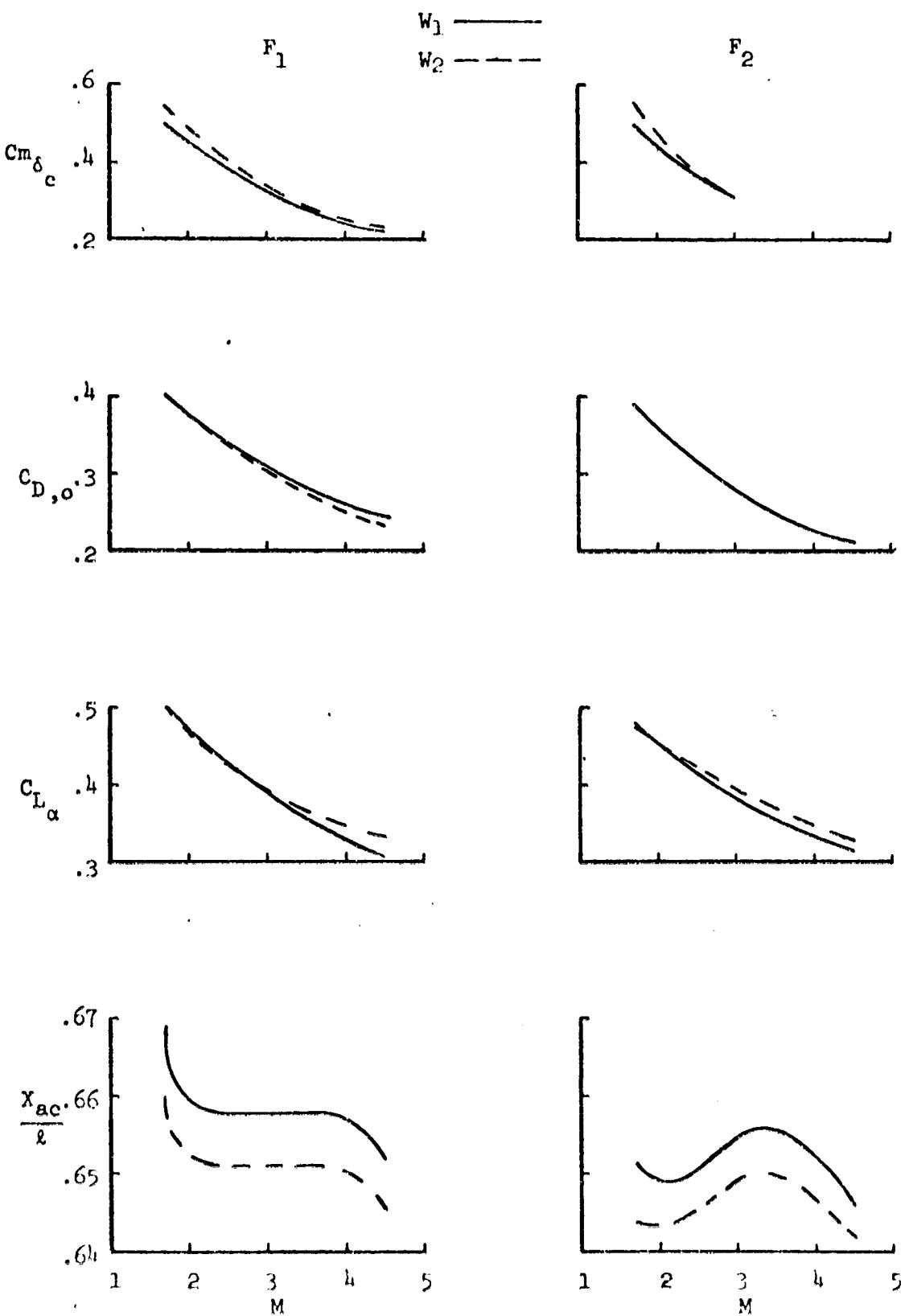
Model details. All dimensions are given in inches and parenthetically in centimeters.

Ref. TM SX-1961



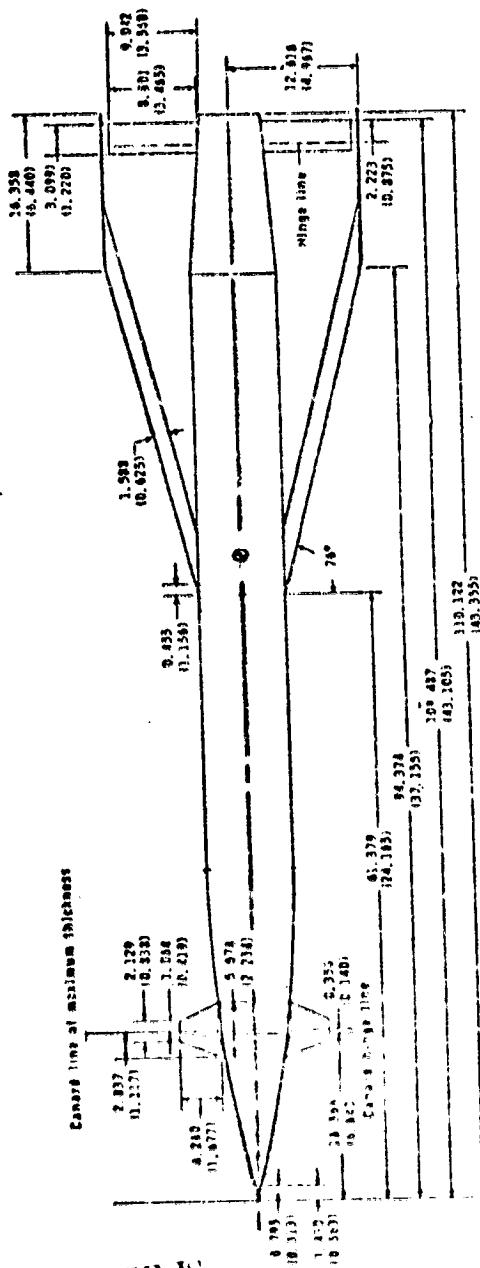
W₂ Wing

(b) C₂ canard and W₂ wing.

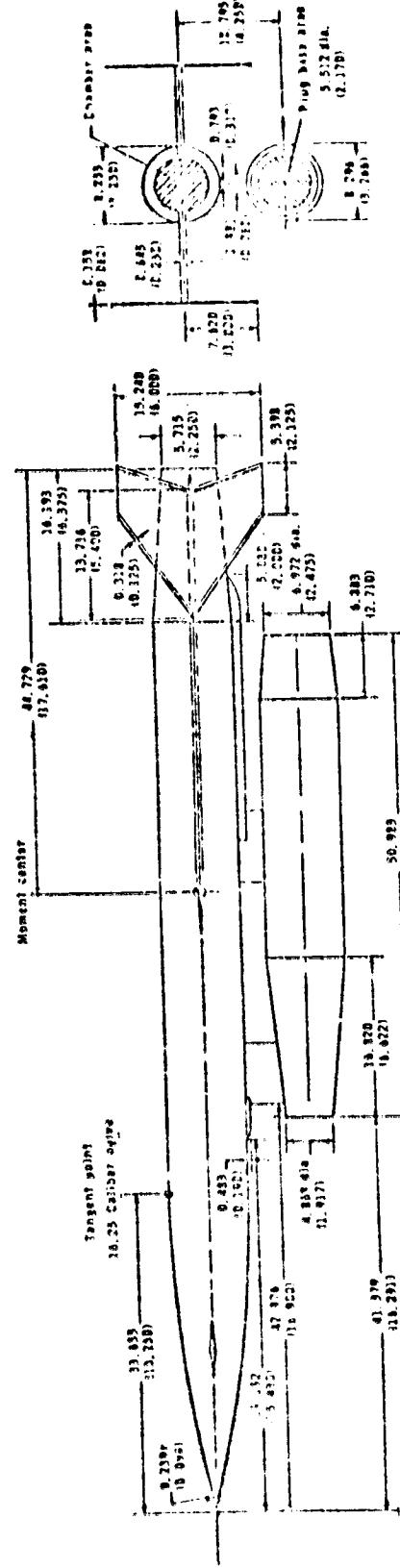


Variation of longitudinal parameters with Mach number; $\alpha = 0$.

Ref. TM SX-1961



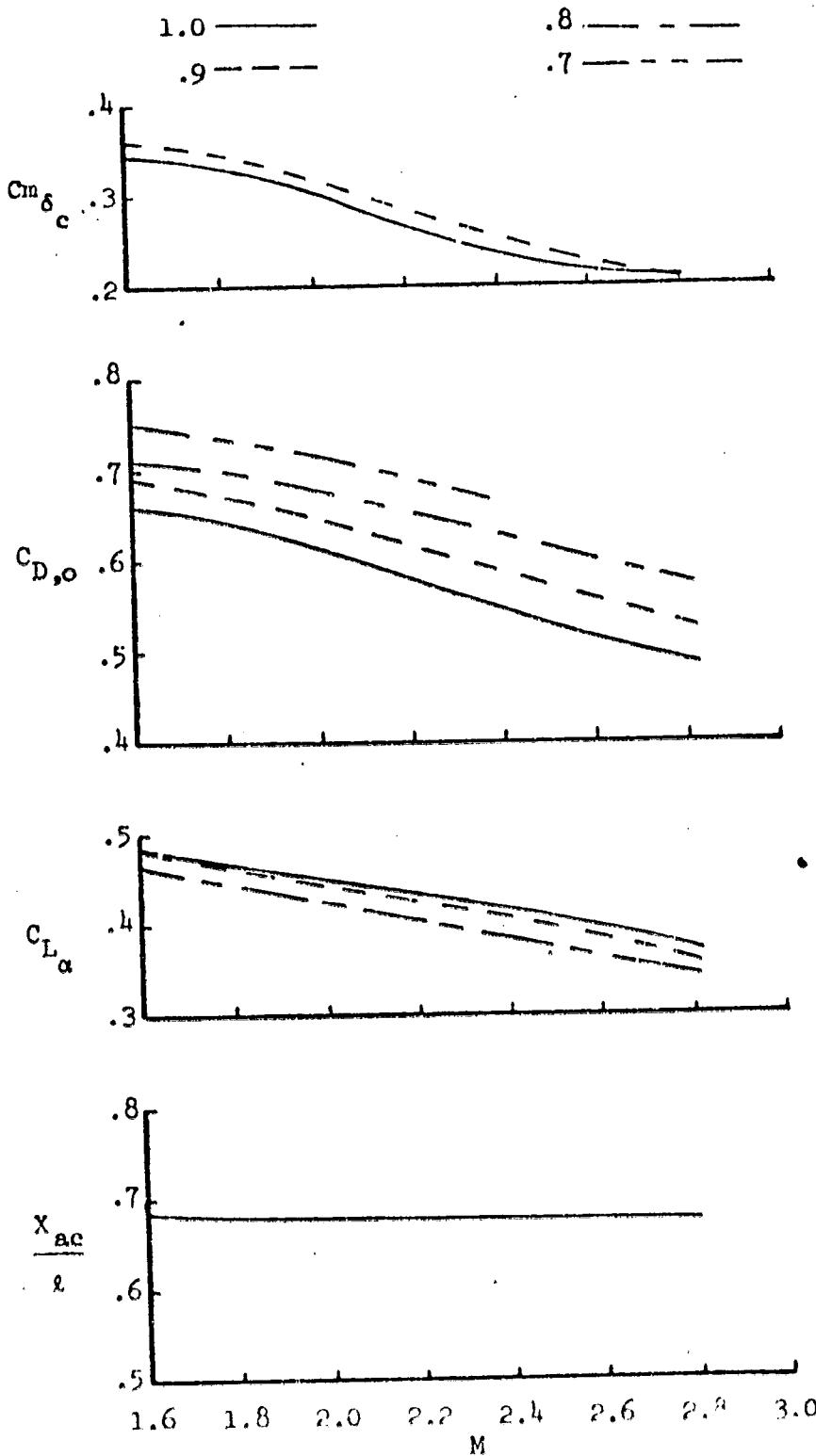
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Details of 1/4-scale model. All dimensions are given in centimeters and parenthetically in inches.

Ref. TW SX-2299

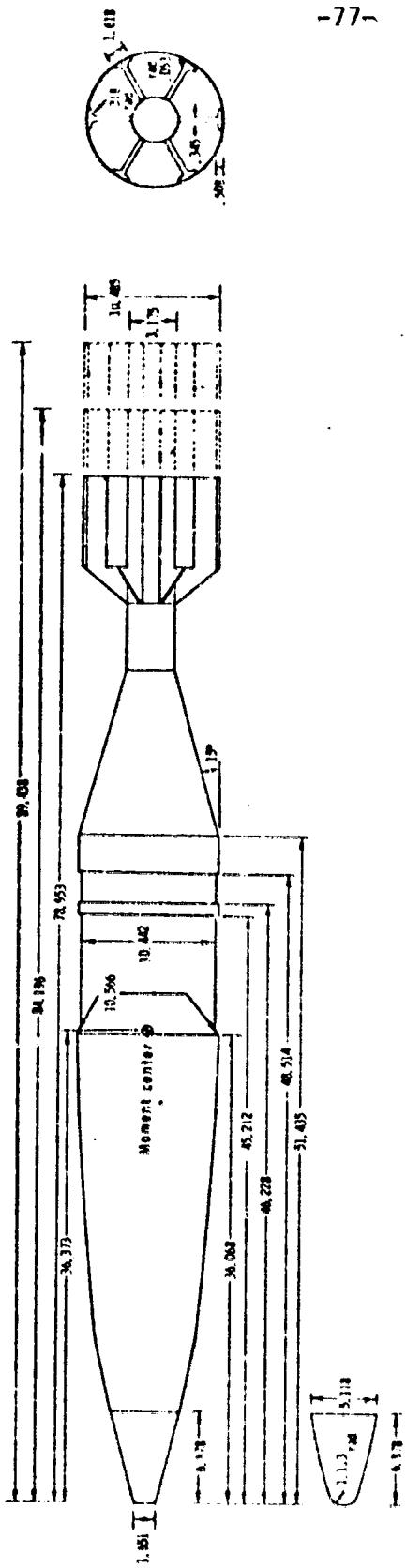
m/m_{∞} = mass flow ratio through nacelle



Variation of longitudinal parameters with Mach numbers; $\alpha=0$.

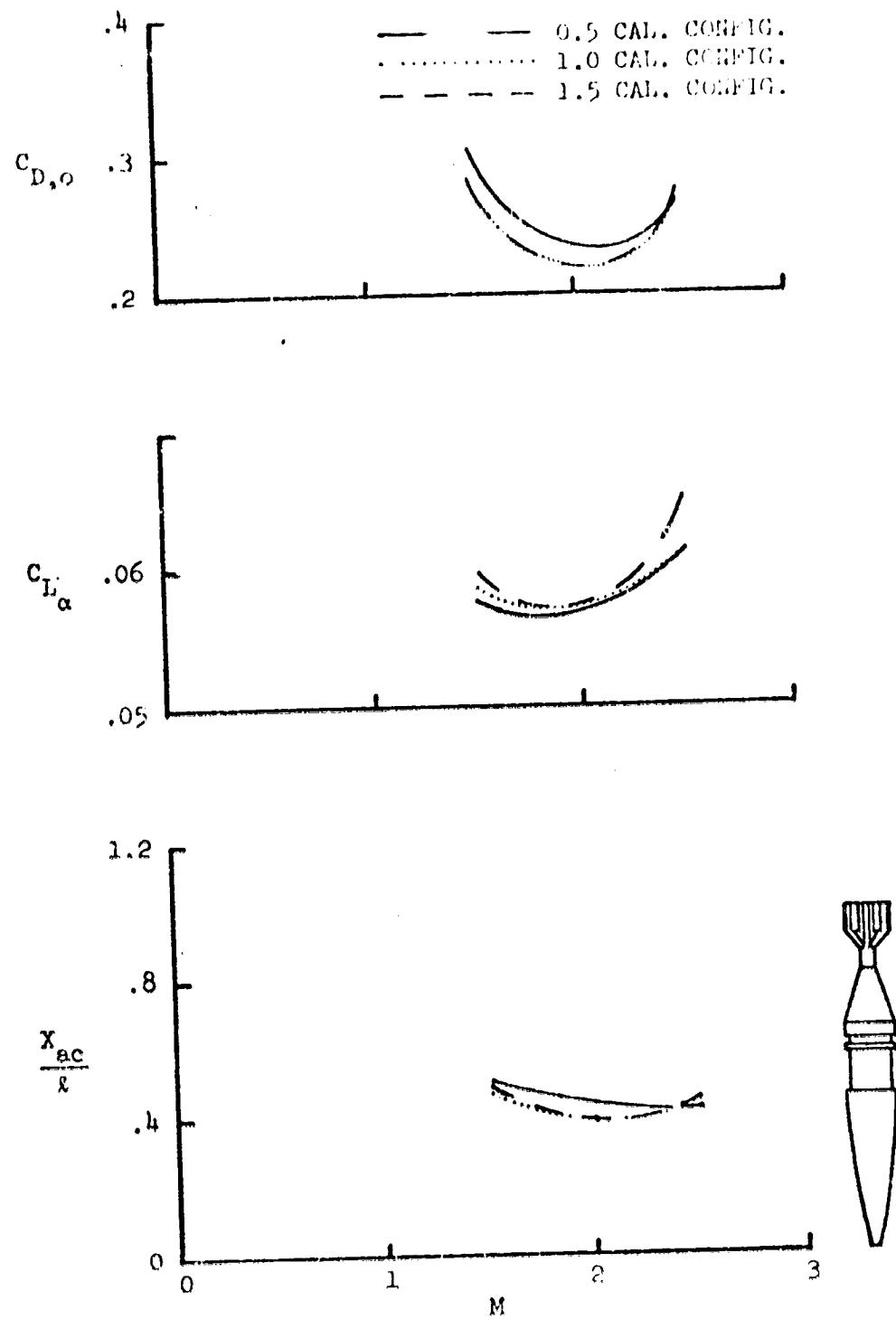
Ref. TM SX-2299

PROJECTILE



Wind-tunnel model of a 105-mm projectile. (Model dimensions are in centimeters.)

Ref. TM X-2831



Variation of longitudinal parameters with Mach number; $\alpha=0^\circ$.

Ref. TM X-2831

LIST OF DOCUMENTS SUMMARIZED

- NACA RM L58C19 INVESTIGATION OF CONTROL EFFECTIVENESS AND STABILITY CHARACTERISTICS OF A MODEL OF A LOW-WING MISSILE WITH INTERDIGITATED TAIL SURFACES AT MACH NUMBERS OF 2.29, 2.97, AND 3.51.
John G. Presnell, Jr., 1958.
- NASA TM X-187 STATIC AERODYNAMIC CHARACTERISTICS OF SEVERAL HYPERSONIC MISSILE-AND-CONTROL CONFIGURATIONS AT A MACH NUMBER OF 4.65.
James D. Church and Ida M. Kirkland, 1960.
- NASA TM X-846 LONGITUDINAL STABILITY AND CONTROL CHARACTERISTICS OF AN AIR-TO-AIR MISSILE CONFIGURATION AT MACH NUMBERS OF 2.30 AND 4.60 AND ANGLES OF ATTACK FROM -45° TO 90° .
Royce L. McKinnely, 1963.
- NASA TM X-1025 SUPERSONIC AERODYNAMIC CHARACTERISTICS OF A CRUCIFORM MISSILE CONFIGURATION WITH LOW-ASPECT-RATIO WINGS AND IN-LINE TAIL CONTROLS.
Dennis E. Fuller and William A. Corlett, 1964.
- NASA TM X-1112 AERODYNAMIC CHARACTERISTICS AT MACH 1.60, 2.00, AND 2.50 OF A CRUCIFORM MISSILE CONFIGURATION WITH IN-LINE TAIL CONTROLS.
William A. Corlett and Dennis E. Fuller, 1965.

NASA TM X-1184 AERODYNAMIC CHARACTERISTICS AT MACH NUMBERS FROM 0.40 TO 2.86 OF A MISSILE MODEL HAVING ALL-MOVABLE WINGS AND INTERDIGITATED TAILS.

Gerald V. Foster and William A. Corlett, 1965.

NASA TM X-1304 AERODYNAMIC CHARACTERISTICS OF A 0.187-SCALE MODEL OF A TARGET MISSILE AT MACH 1.80 TO 2.16.

William A. Corlett, 1966.

NASA TM X-1309 AERODYNAMIC CHARACTERISTICS OF A MANEUVERABLE MISSILE WITH CRUCIFORM WINGS AND IN-LINE CANARD SURFACES AT MACH NUMBERS FROM 0.50 TO 4.63.

William A. Corlett, 1966.

NASA TM X-1332 AERODYNAMIC CHARACTERISTICS AT MACH NUMBERS OF 3.95 AND 4.63 FOR A MISSILE MODEL HAVING ALL-MOVABLE WINGS AND INTERDIGITATED TAILS.

M. Leroy Spearman and William A. Corlett, 1967.

NASA TM X-1352 AERODYNAMIC CHARACTERISTICS AT MACH NUMBERS FROM 1.50 TO 4.63 OF A MANEUVERABLE MISSILE WITH IN-LINE CRUCIFORM WINGS AND CANARD SURFACES.

M. Leroy Spearman and William A. Corlett, 1967.

NASA TM X-1416 AERODYNAMIC CHARACTERISTICS OF A WINGED CRUCIFORM MISSILE CONFIGURATION WITH AFT TAIL CONTROLS AT MACH NUMBERS FROM 1.60 TO 4.63.

M. Leroy Spearman and William A. Corlett, 1967.

NASA TM X-1491 SUPERSONIC AERODYNAMIC CHARACTERISTICS OF A MODEL OF AN AIR-TO-GROUND MISSILE.

Clyde Hayes, 1968.

NASA TM X-1492 AERODYNAMIC CHARACTERISTICS AT MACH 2.50 OF A CRUCIFORM
MISSILE CONFIGURATION WITH IN-LINE INLETS, WINGS, AND
TAIL SURFACES.

Dennis E. Fuller and Celia S. Richardson, 1968.

NASA TM SX-1531 AERODYNAMIC CHARACTERISTICS OF A TARGET DRONE VEHICLE
AT MACH NUMBERS FROM 1.57 TO 2.10.

A. B. Blair, Jr., and Roger H. Fournier, 1968.

NASA TM X-1538 STABILITY AND CONTROL CHARACTERISTICS AT MACH 1.57 TO
2.16 OF A TARGET DRONE MODEL WITH AN UNDERSLUNG INLET.

A. B. Blair, Jr., and Melvin M. Carmel, 1968.

NASA TM X-1751 AERODYNAMIC CHARACTERISTICS OF A MODIFIED MISSILE MODEL
WITH TRAPEZOIDAL WINGS AND AFT TAIL CONTROLS AT MACH
NUMBERS OF 2.50 TO 4.63.

William A. Corlett, 1969.

NASA TM X-1834 AERODYNAMIC CHARACTERISTICS OF A CRUCIFORM-WING MISSILE
MODEL WITH A SYSTEMATIC VARIATION OF CANARD AND TAIL
LOCATIONS AT MACH 1.60 TO 4.63.

William A. Corlett.

NASA TM X-1839 EFFECTS OF WING PLANFORM ON THE STATIC AERODYNAMICS OF
A CRUCIFORM WING-BODY MISSILE AT MACH NUMBERS 1.50 TO 2.86.
Roger H. Fournier and M. Leroy Spearman, 1971.

NASA TM SX-1961 EFFECTS OF ADDITIONAL REVISIONS ON THE AERODYNAMIC
CHARACTERISTICS OF A TARGET DRONE VEHICLE AT MACH NUMBERS
FROM 1.70 TO 4.63.

A. B. Blair, Jr., and Dorothy H. Tudor, 1970.

NASA TM X-2289 EFFECTS OF NOSE BLUNTNES ON THE STATIC AERODYNAMIC CHARACTERISTICS OF A CRUCIFORM-WING MISSILE AT MACH NUMBERS 1.50 TO 2.86.

Roger H. Fournier and M. Leroy Spearman, 1971.

NASA TM SX-2299 AERODYNAMIC CHARACTERISTICS AT MACH NUMBERS FROM 1.60 TO 2.86 OF A TARGET-DRONE VEHICLE WITH UNDERSLUNG ENGINE NACELLE.

A. B. Blair, Jr., 1971.

NASA TM X-2367 LONGITUDINAL AERODYNAMIC CHARACTERISTICS AT MACH 1.50 TO 4.63 OF A MISSILE MODEL EMPLOYING VARIOUS CANARDS AND A TRAILING-EDGE FLAP CONTROL.

Charles D. Trescot, Jr., 1971.

NASA TM X-2491 EFFECTS OF STRAP-ON BOOSTERS ON THE AERODYNAMIC CHARACTERISTICS OF A SIMULATED LAUNCH VEHICLE AT MACH NUMBERS FROM 1.50 TO 2.86.

M. Leroy Spearman and Roger H. Fournier, 1972.

NASA TM X-2774 EFFECTS OF FIN PLANFORM ON THE AERODYNAMIC CHARACTERISTICS OF A WINGLESS MISSILE WITH AFT CRUCIFORM CONTROLS AT MACH 1.60, 2.36, AND 2.86.

Charles D. Trescot, Jr., Gerald V. Foster, and C. Donald Babb, 1973.

NASA TM X-2780 AERODYNAMIC CHARACTERISTICS AT MACH 0.60 TO 4.63 OF TWO CRUCIFORM MISSILE MODELS, ONE HAVING TRAPEZOIDAL WINGS WITH CANARD CONTROLS AND THE OTHER HAVING DELTA WINGS WITH TAIL CONTROLS.

William A. Corlett and Dorothy T. Howell, 1973.

NASA TM X-2831 EFFECT OF NOSE SHAPE AND TAIL LENGTH ON SUPERSONIC STABILITY CHARACTERISTICS OF A PROJECTILE.

Wallace C. Sawyer and Ida K. Collins, 1973.

NASA TM X-3070 STABILITY AND CONTROL CHARACTERISTICS AT MACH NUMBERS FROM 0.20 TO 4.63 OF A CRUCIFORM AIR-TO-AIR MISSILE WITH TRIANGULAR CANARD CONTROLS AND A TRAPEZOIDAL WING.

Ernald B. Graves and Roger H. Fournier, 1974.

TM X-71984 STABILITY AND CONTROL CHARACTERISTICS OF A MONOPLANE MISSILE WITH LARGE DELTA WINGS AND VARIOUS TAIL CONTROLS AT MACH 1.90 TO 2.86.

Lloyd S. Jernell, 1974.

TN D-7069 AERODYNAMIC CHARACTERISTICS OF A SWEPT-WING CRUISE MISSILE AT MACH NUMBERS FROM 0.50 TO 2.86.

M. Leroy Spearman and Ida K. Collins, 1972.

LONGITUDINAL PARAMETERS AT MACH NUMBER 4.65; $\alpha=0^\circ$

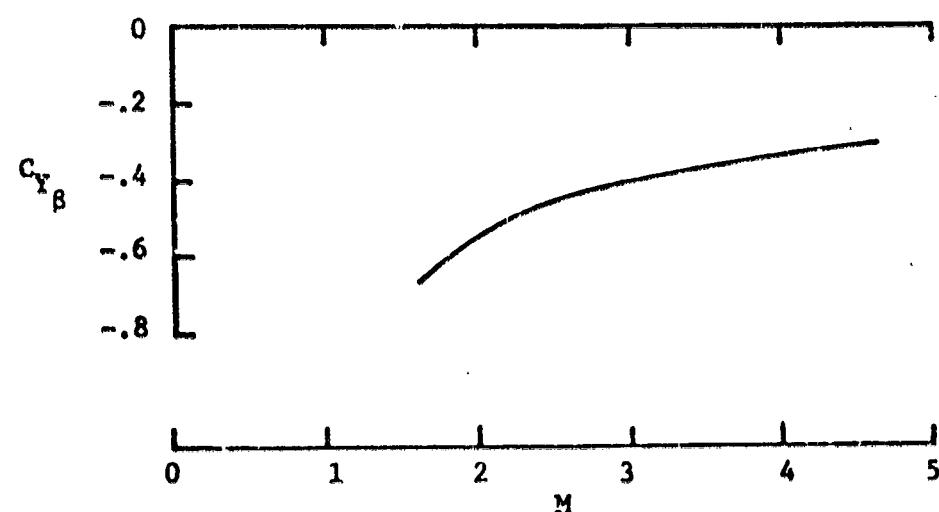
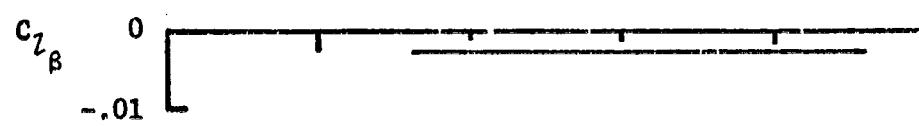
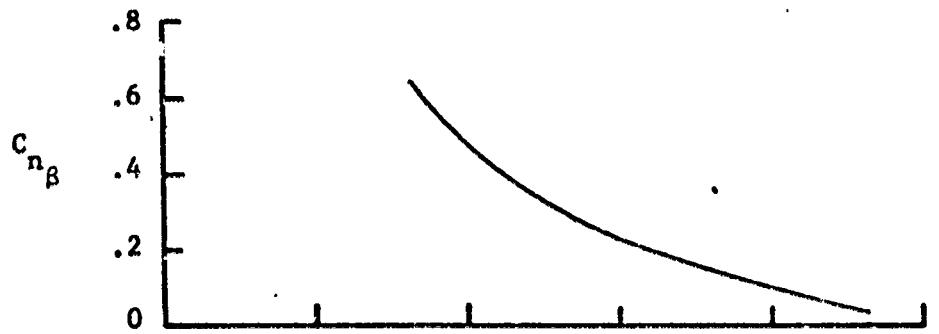
CONFIGURATION	C_{n_δ}	$C_{D,o}$	C_{L_α}	$\frac{x_{ac}}{L}$
Delta Fins and Trailing-Edge Controls	-0.017	0.12	0.134	0.637
Large Canard Controls with Flared Skirt	0.106	0.36	0.175	0.593
Small Canard Controls with Flared Skirt	0.143	0.34	0.150	0.583
Small Canard Controls without Flared Skirt	—	0.18	0.105	0.445

SIDESLIP DERIVATIVES AT MACH NUMBER 4.65; $\alpha=0^\circ$

CONFIGURATION	C_{n_β}	C_{l_f}	C_{Y_β}
Delta Fins and Trailing-Edge Controls	-0.266	0	-0.153
Large Canard Controls with Flared Skirt	-0.418	0	-0.186
Small Canard Controls with Flared Skirt	-0.390	0	-0.177
Small Canard Controls without Flared Skirt	-0.433	0	-0.134

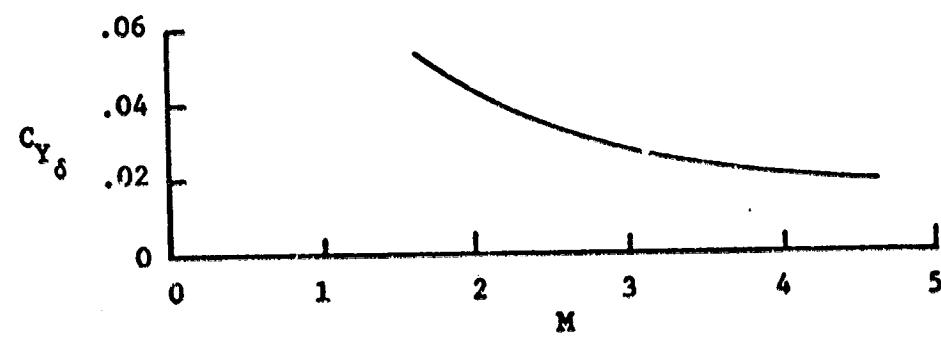
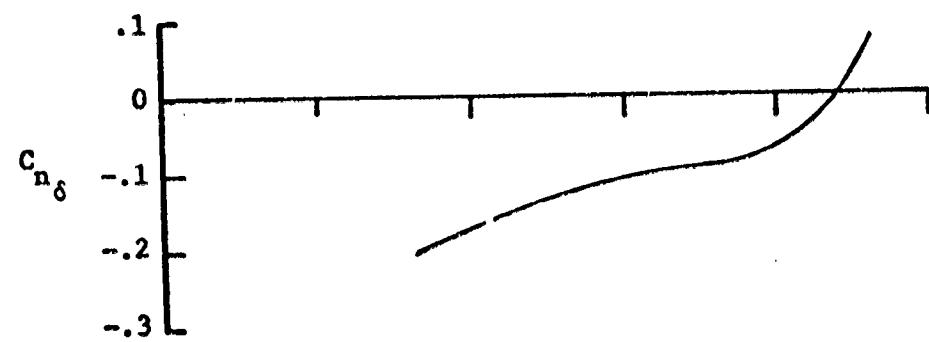
DIRECTIONAL AND LATERAL CONTROL EFFECTIVENESS
AT MACH NUMBER OF 4.65; $\alpha=0^\circ$

CONFIGURATION	C_{n_δ}	C_{l_δ}	C_{Y_δ} roll	C_{Y_δ} yaw
Delta Fins and Trailing Edge Controls	-0.0133	0.008	-0.020	0.0067
Small Canard Controls with Flared Skirt	—	0.052	-0.030	—



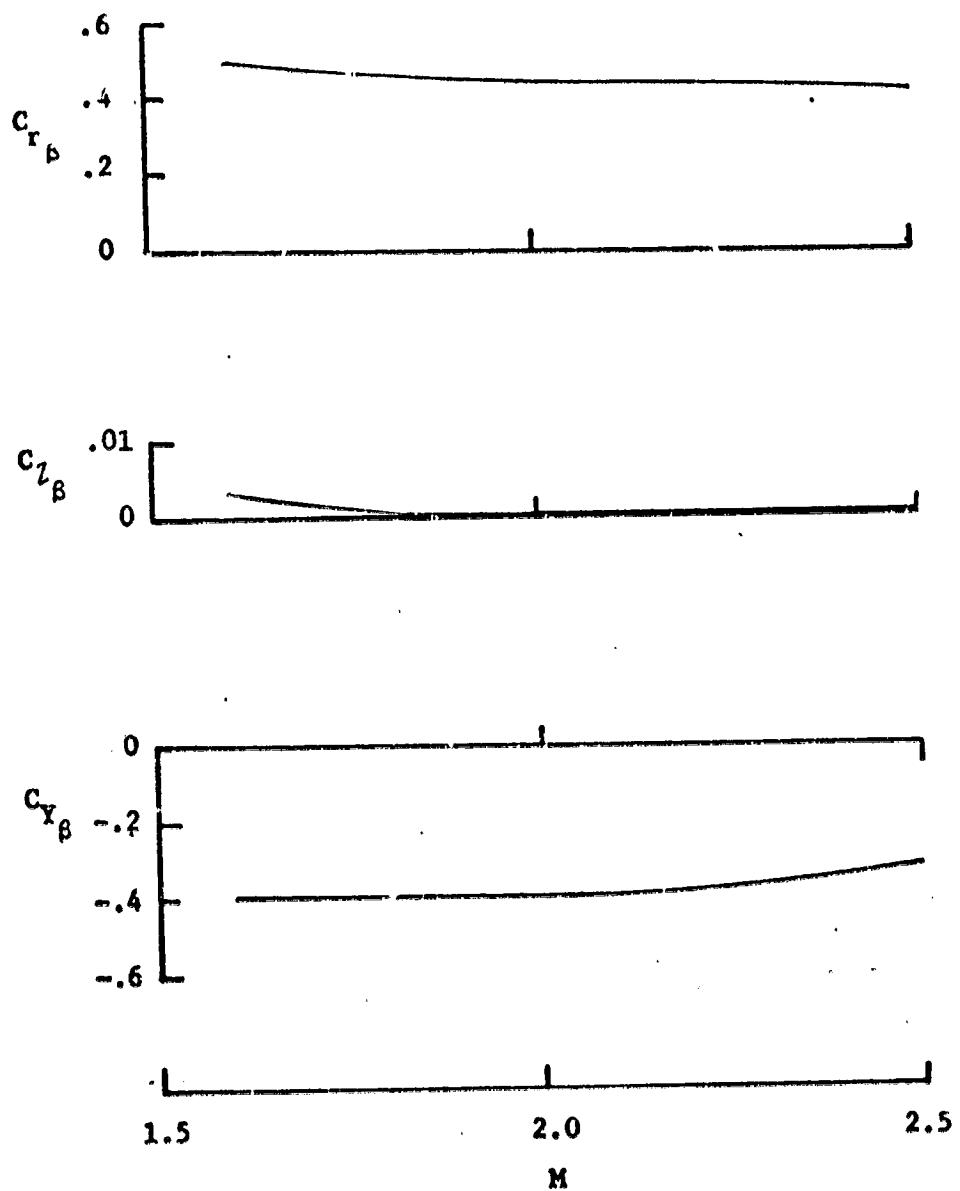
Variation of sideslip derivatives with Mach number; $\alpha \approx 0^\circ$.

Ref. TM X-1025



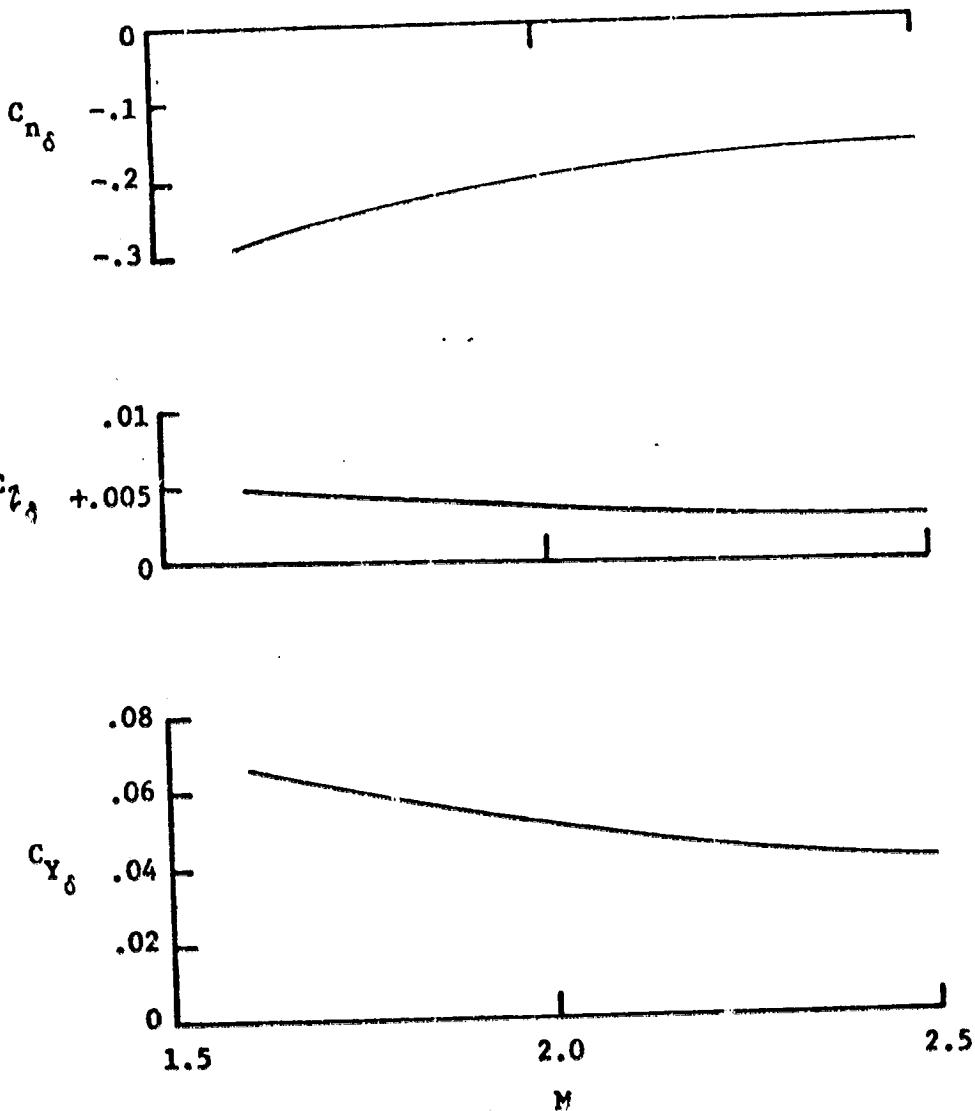
Directional control effectiveness; $\alpha \approx 0^\circ$.

Ref. TM X-1025



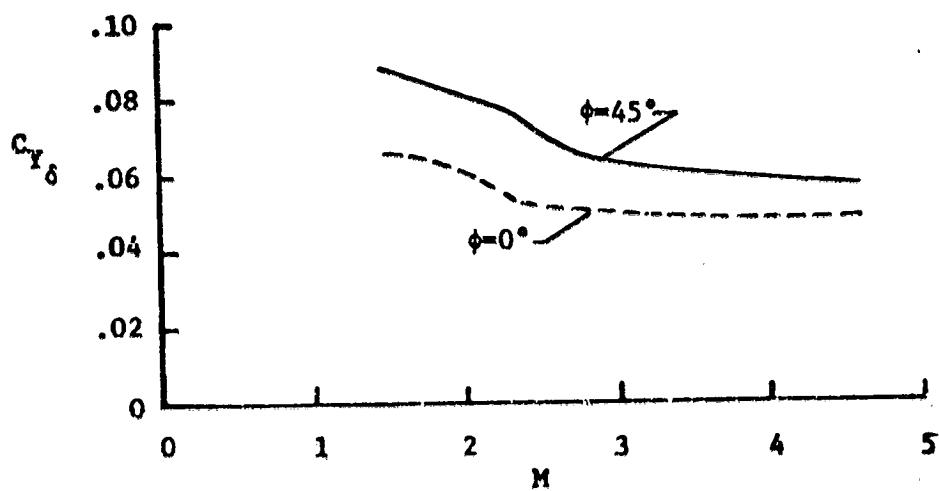
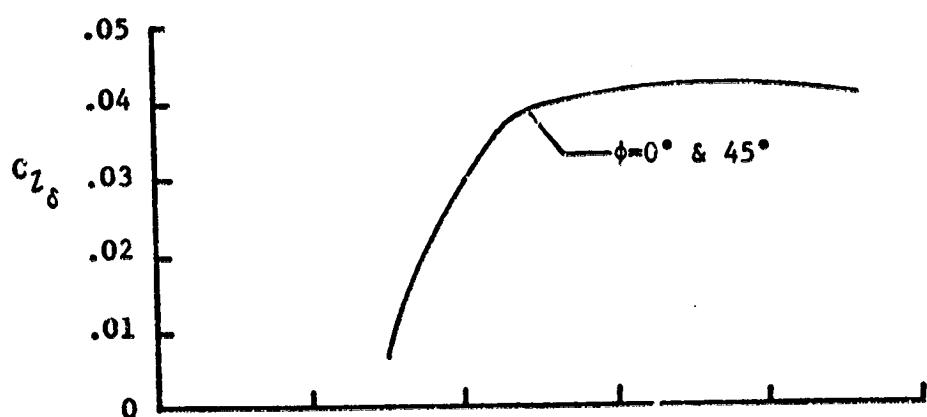
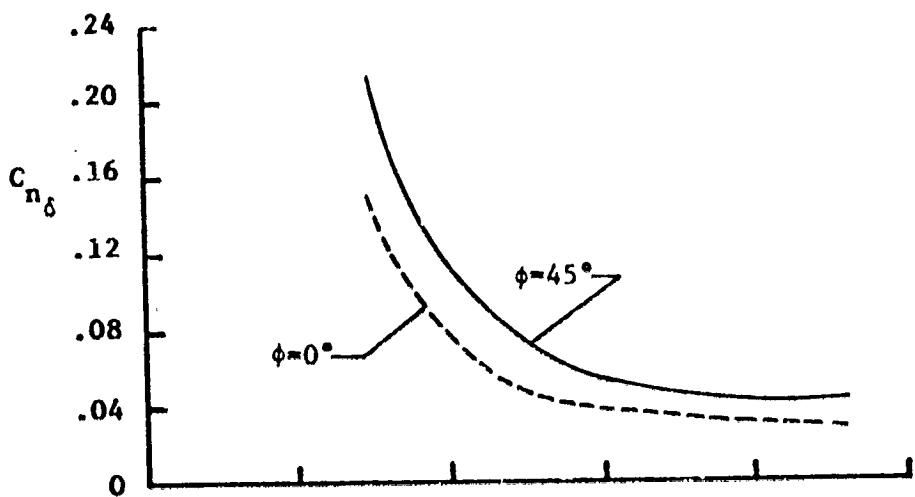
Variation of sideslip derivatives with Mach number; $\alpha=0^\circ$.

Ref. TM X-1112



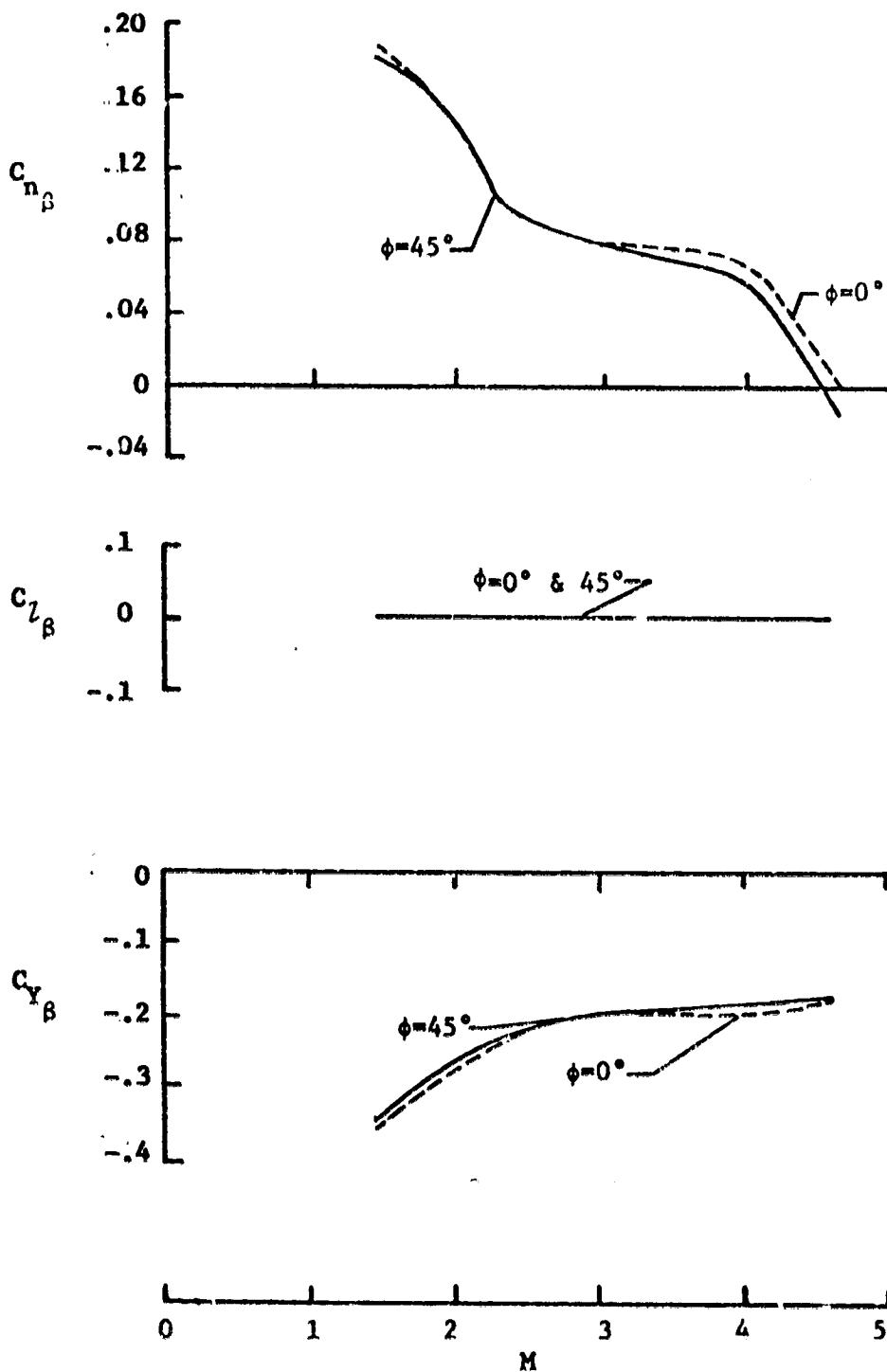
Directional and lateral control effectiveness; $\alpha=0^\circ$.

Ref. TM X-1112



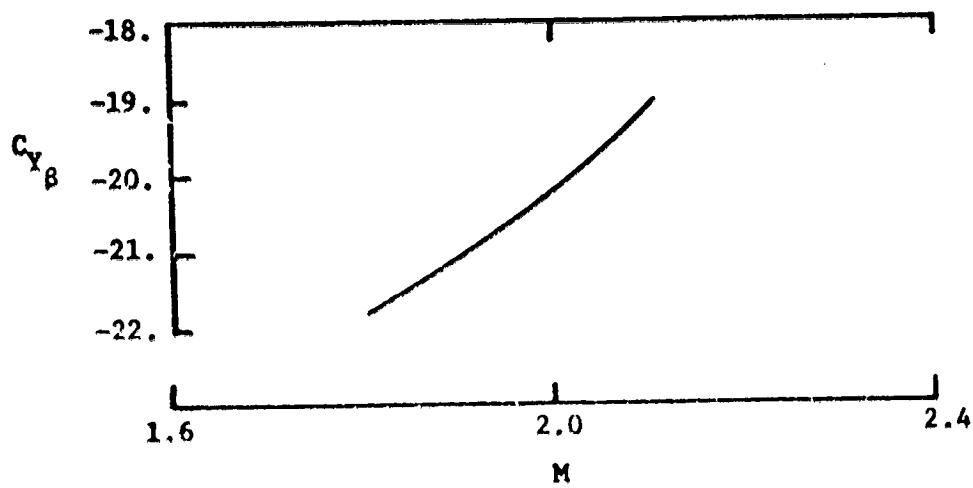
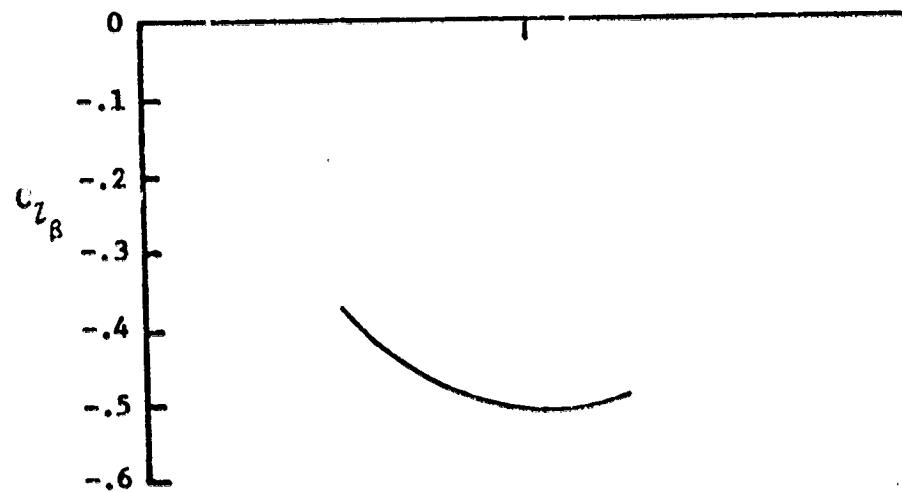
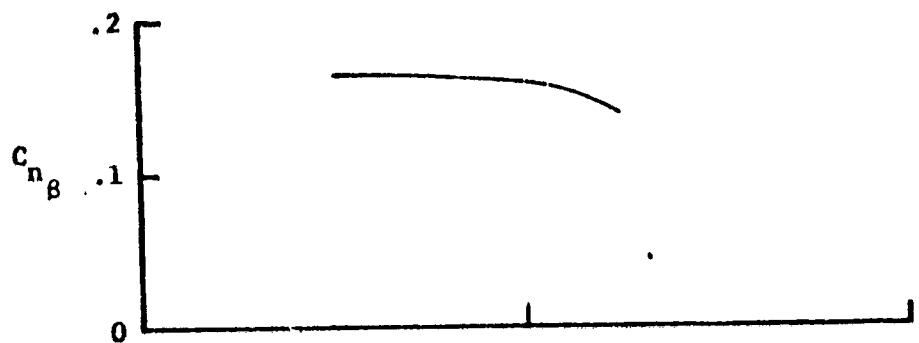
Directional and lateral control effectiveness; $\alpha=0^\circ$.

Ref. TM X-1184, TM X-1332



Variation of sideslip derivatives with Mach number; $\alpha=0^\circ$.

Ref. TM X-1184, TM X-1332



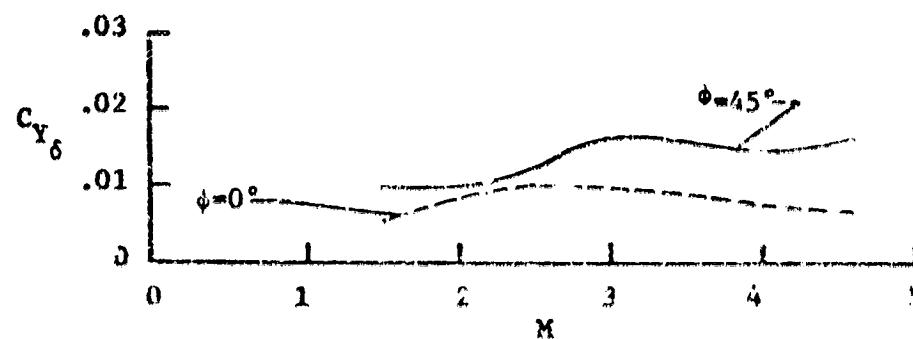
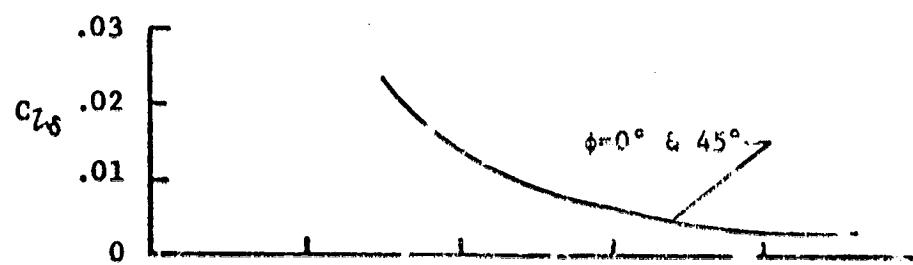
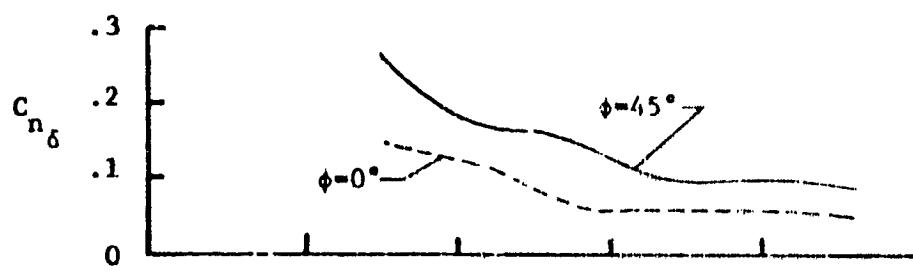
Variation of sideslip derivatives with Mach number; $\alpha=0^\circ$.

Ref. TM X-1304

DIRECTION AND LATERAL CONTROL EFFECTIVENESS

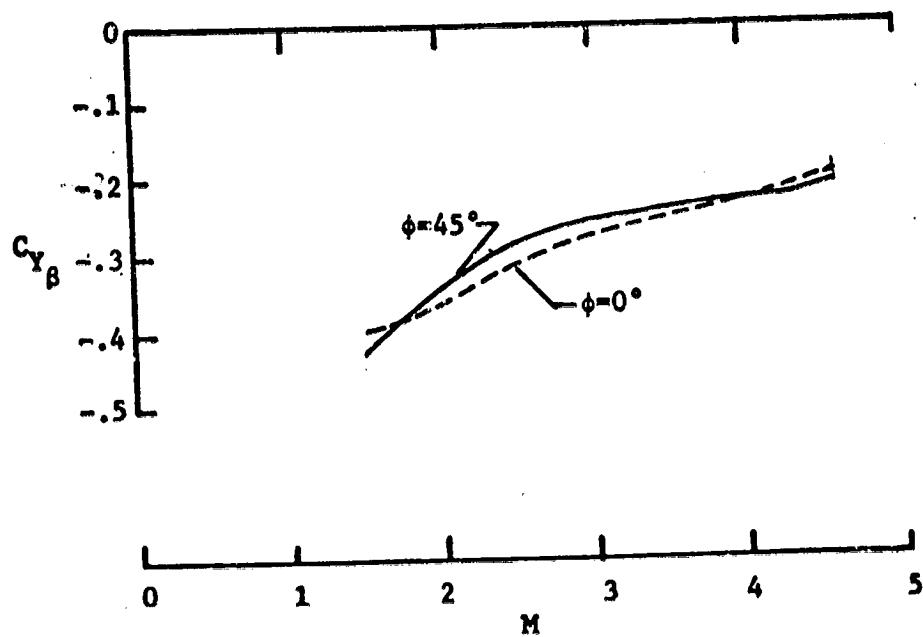
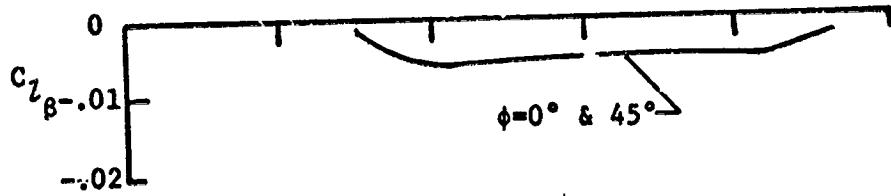
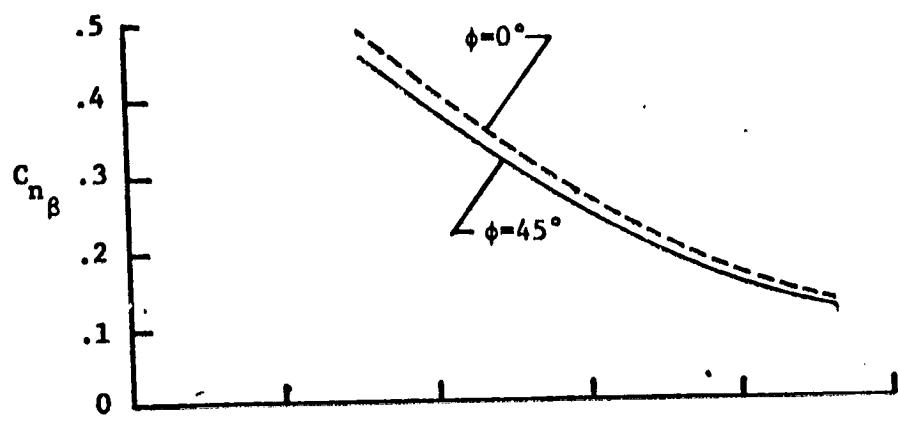
Mach No.	Yaw Control			Roll Control		
	$C_{n\delta}$	$C_{l\delta}$	$C_{y\delta}$	$C_{n\delta}$	$C_{l\delta}$	$C_{y\delta}$
1.80	-.161	.032	.040	.437	.102	-.075
2.00	-.215	.027	.040	.437	.075	-.118

Ref. TM X-1304



Directional and lateral control effectiveness; $\alpha=0^\circ$.

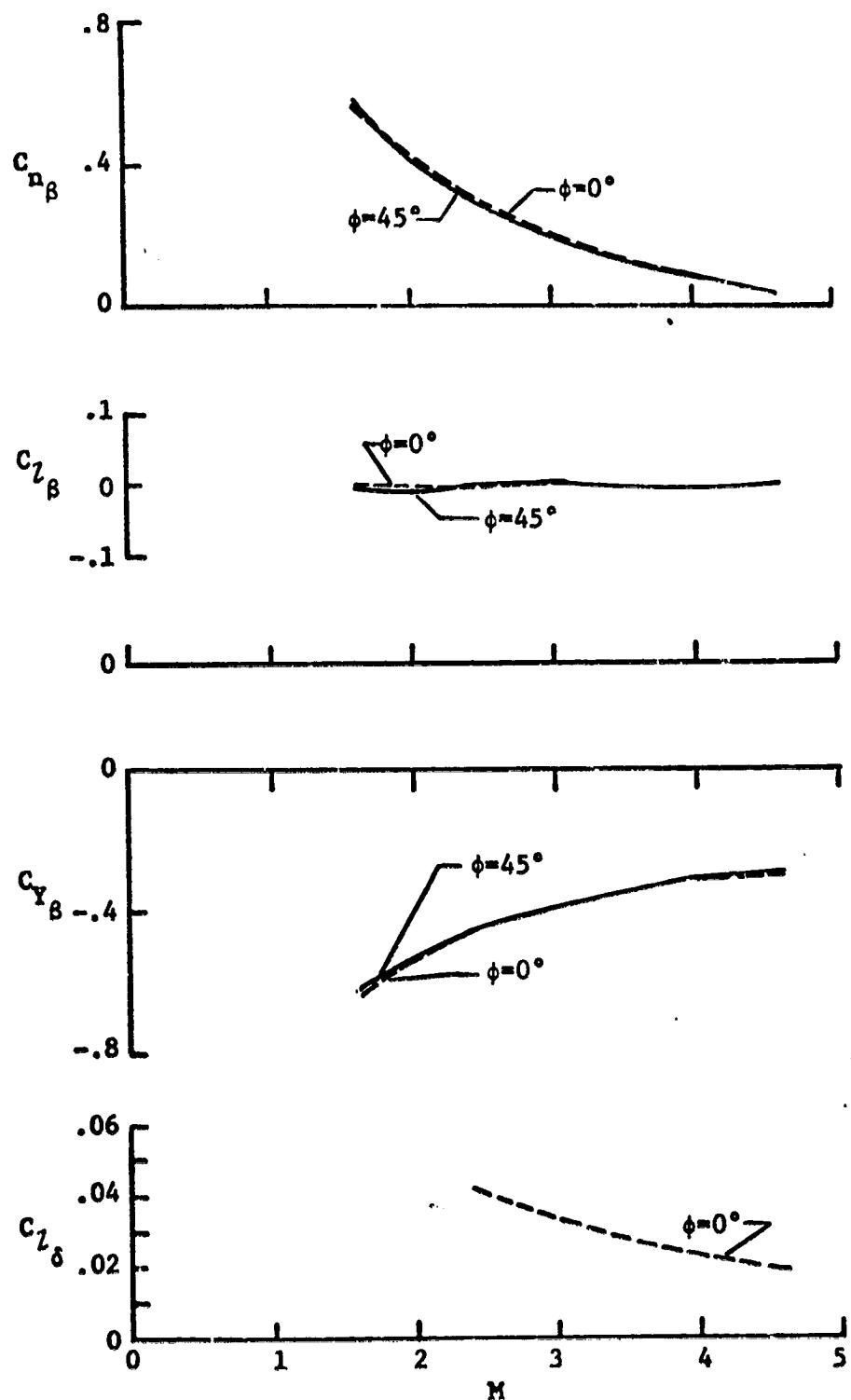
Ref. TM X-1303, TM X-1352



Variation of sideslip derivatives with Mach number; $\alpha=0^\circ$.

Ref. TM X-1309, TM X-1352

C - 2



Variation of sideslip derivatives and roll control effectiveness with Mach number; $\alpha=0^\circ$.

Ref. TM X-1416

SIDESLIP DERIVATIVES AND ROLL CONTROL EFFECTIVENESS
AT MACH NUMBER 2.5 WITH INLETS COVERED: $\alpha=0^\circ$.

$\phi = 0^\circ$

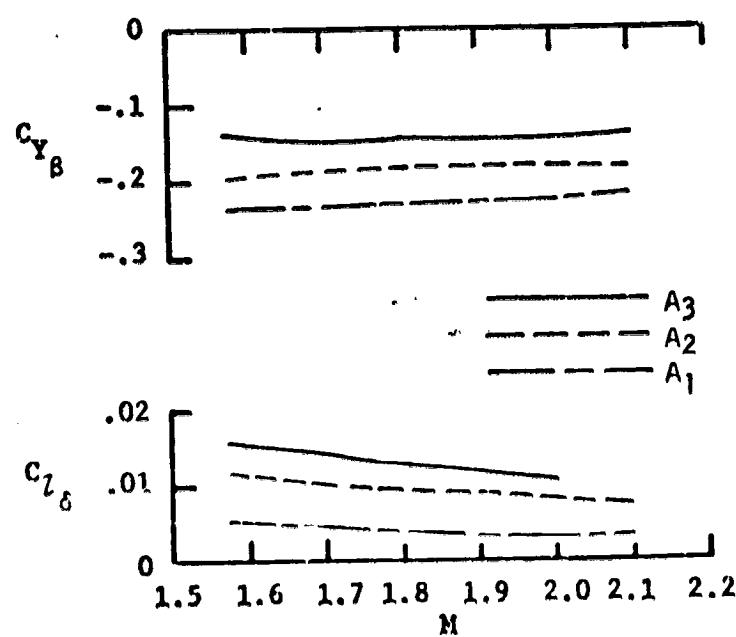
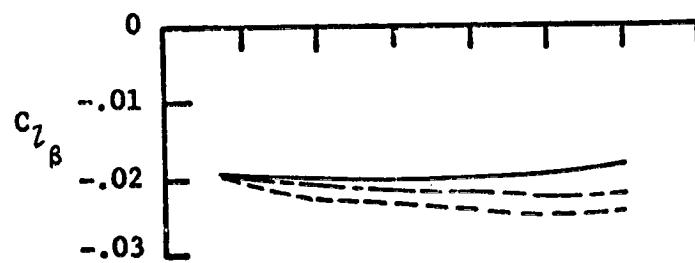
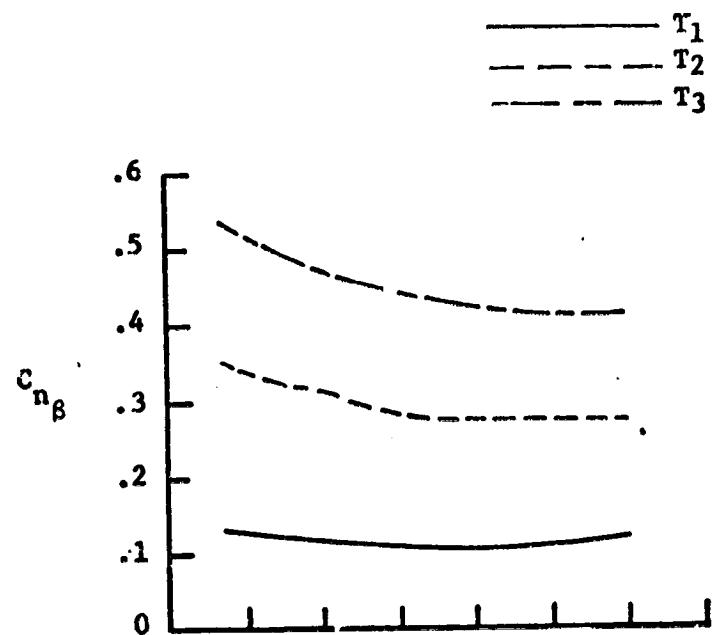
Configuration	$C_{n\beta}$	$C_{l\beta}$	$C_{y\beta}$	$C_{l\delta_{roll}}^*$
Wing 1, Tail 1	.1008	0	-.147	—
Wing 1, Tail 1, Popout Fin	.1568	0	-.163	.0118
Wing 2, Tail 1	.0560	0	-.137	.0127
Wing 3, Tail 1, End Plate	.1344	0	-.155	—

* Horizontal tails were deflected.

$\phi = 45^\circ$

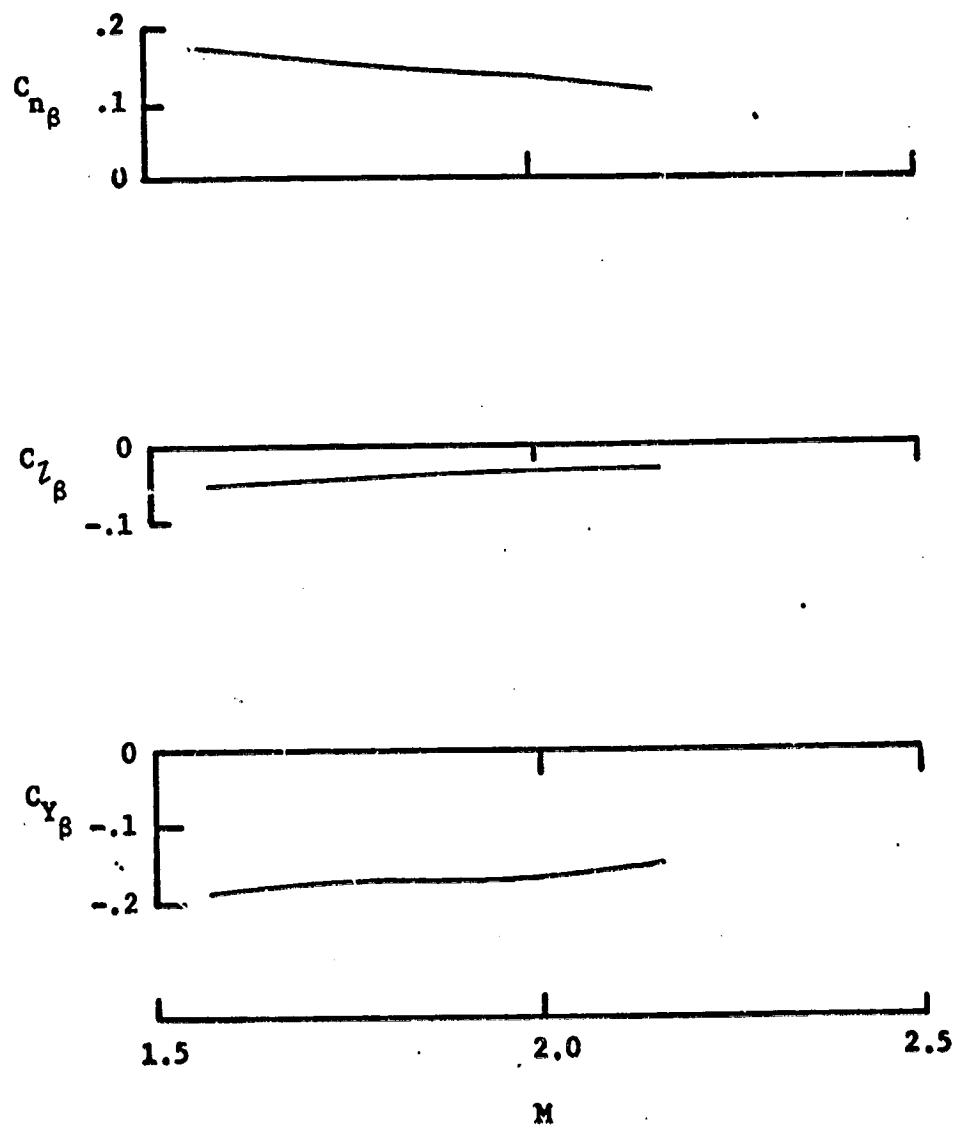
	$C_{n\beta}$	$C_{l\beta}$	$C_{y\beta}$	$C_{l\delta_{roll}}^*$
Wing 1, Tail 1	.0974	0	-.142	—
Wing 1, Tail 1, Popout Fin	.1456	0	-.152	.0235
Wing 2, Tail 1	.0482	0	-.125	.0252
Wing 3, Tail 1, End Plate	.1378	0	-.156	—
Wing 4, Tail 2	—	—	—	.0224

* All four tails were deflected.



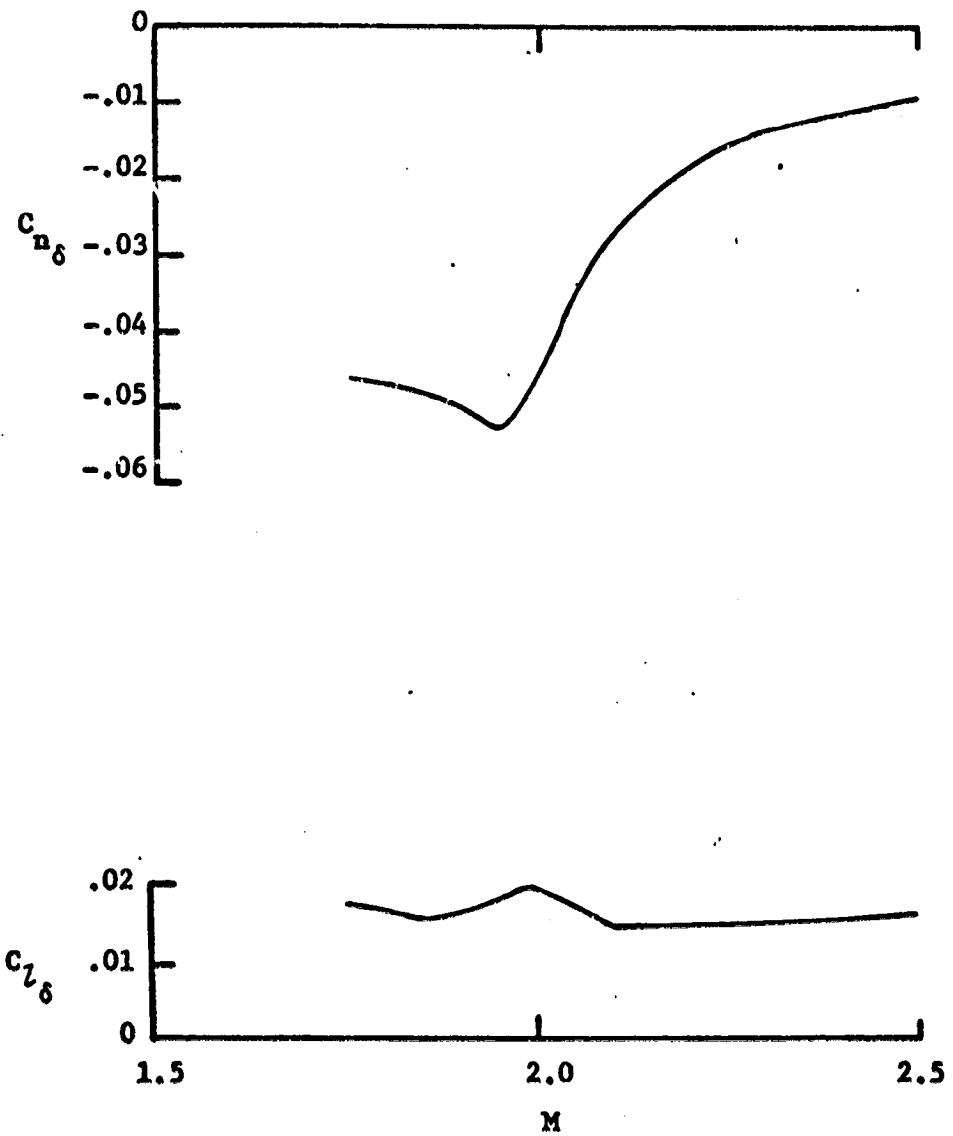
Variation of sideslip derivatives and roll control effectiveness with Mach number; $\alpha=0^\circ$.

Ref. TM SX-1531



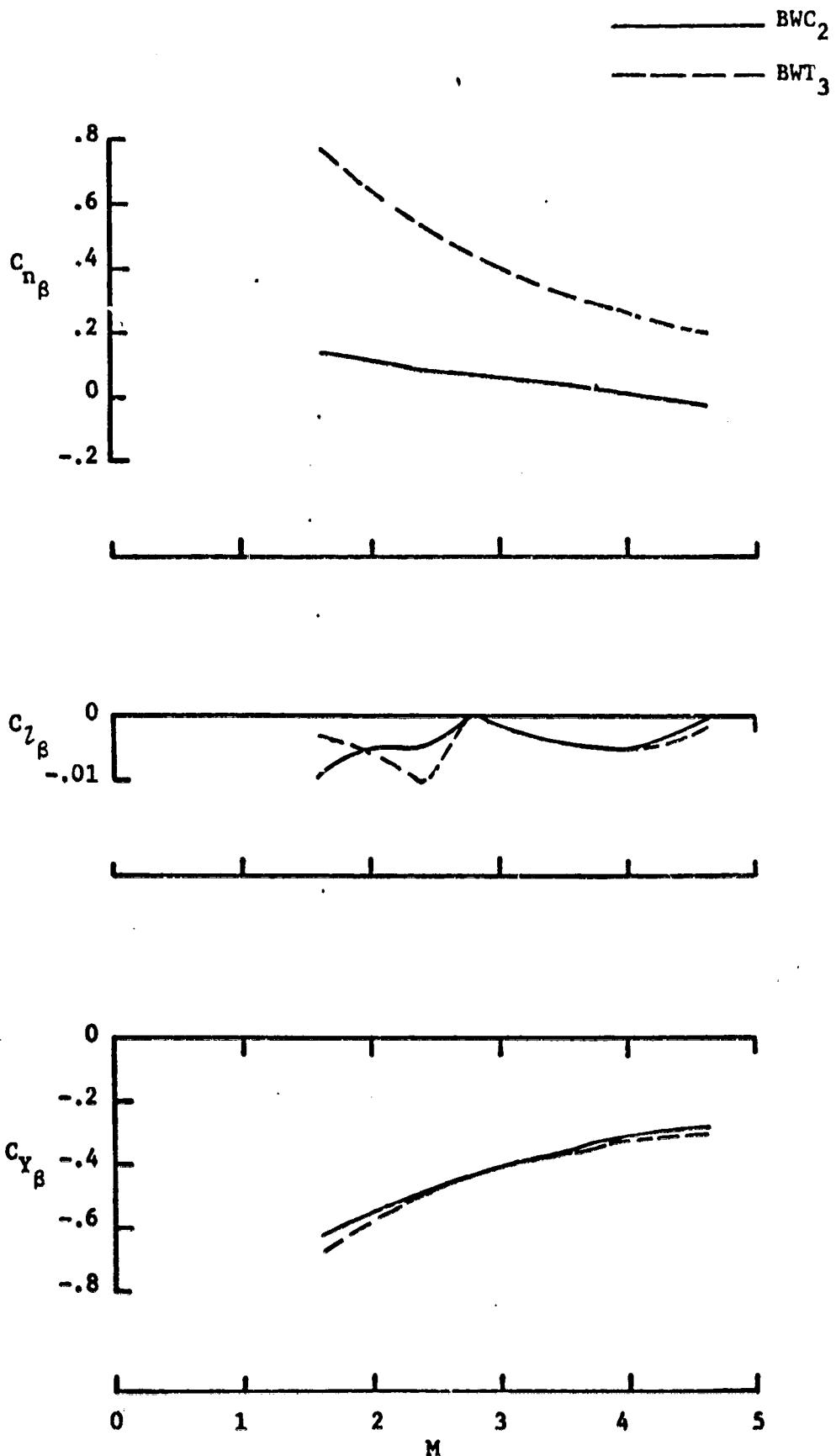
Variation of sideslip derivatives with Mach number; $\alpha=0^\circ$.

Ref. TM X-1538



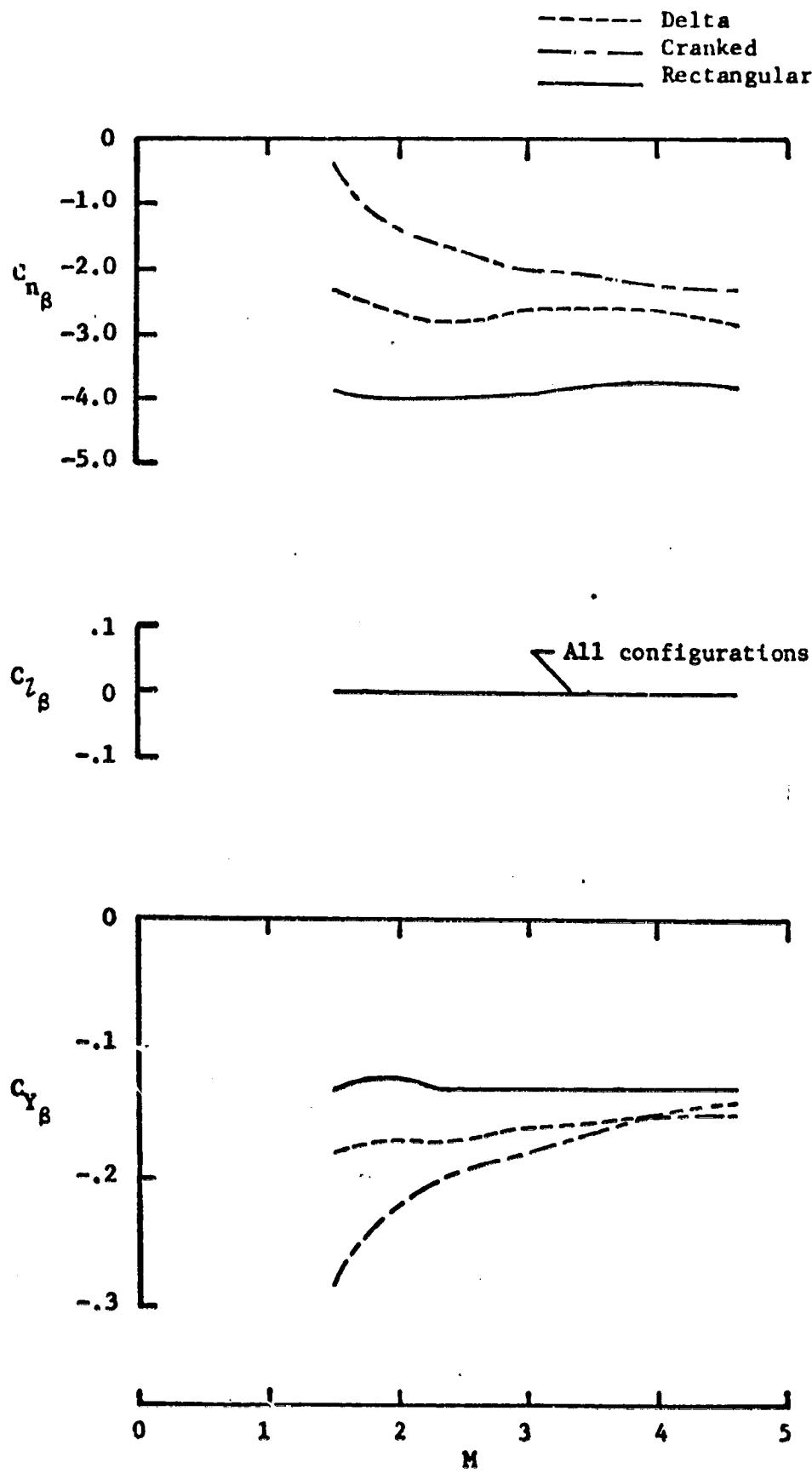
Directional and lateral control effectiveness; $\alpha=0^\circ$.

Ref. TM X-1538

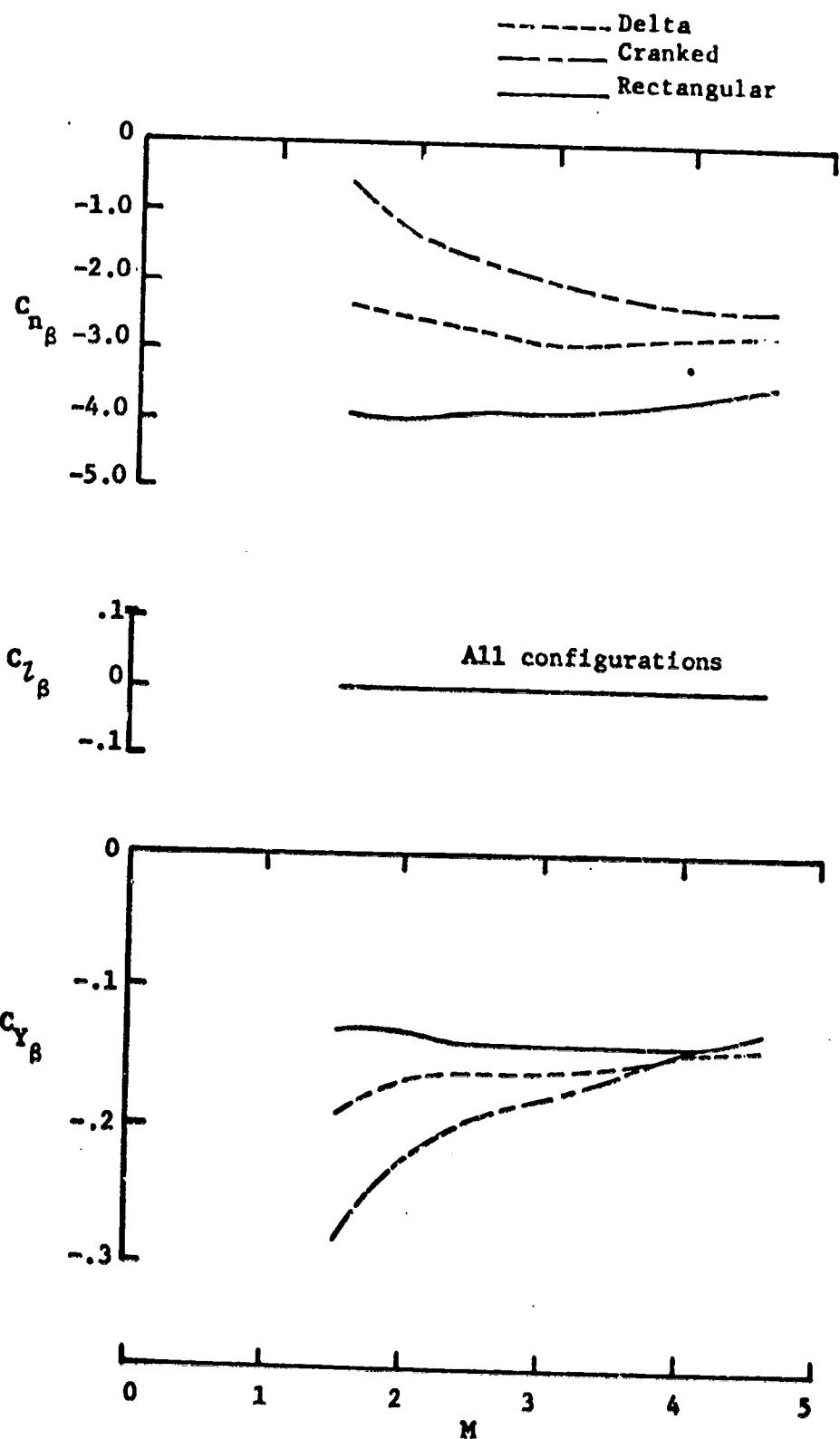


Variation of sideslip derivatives with Mach number; $\alpha=0^\circ$.

Ref. TM X-1834

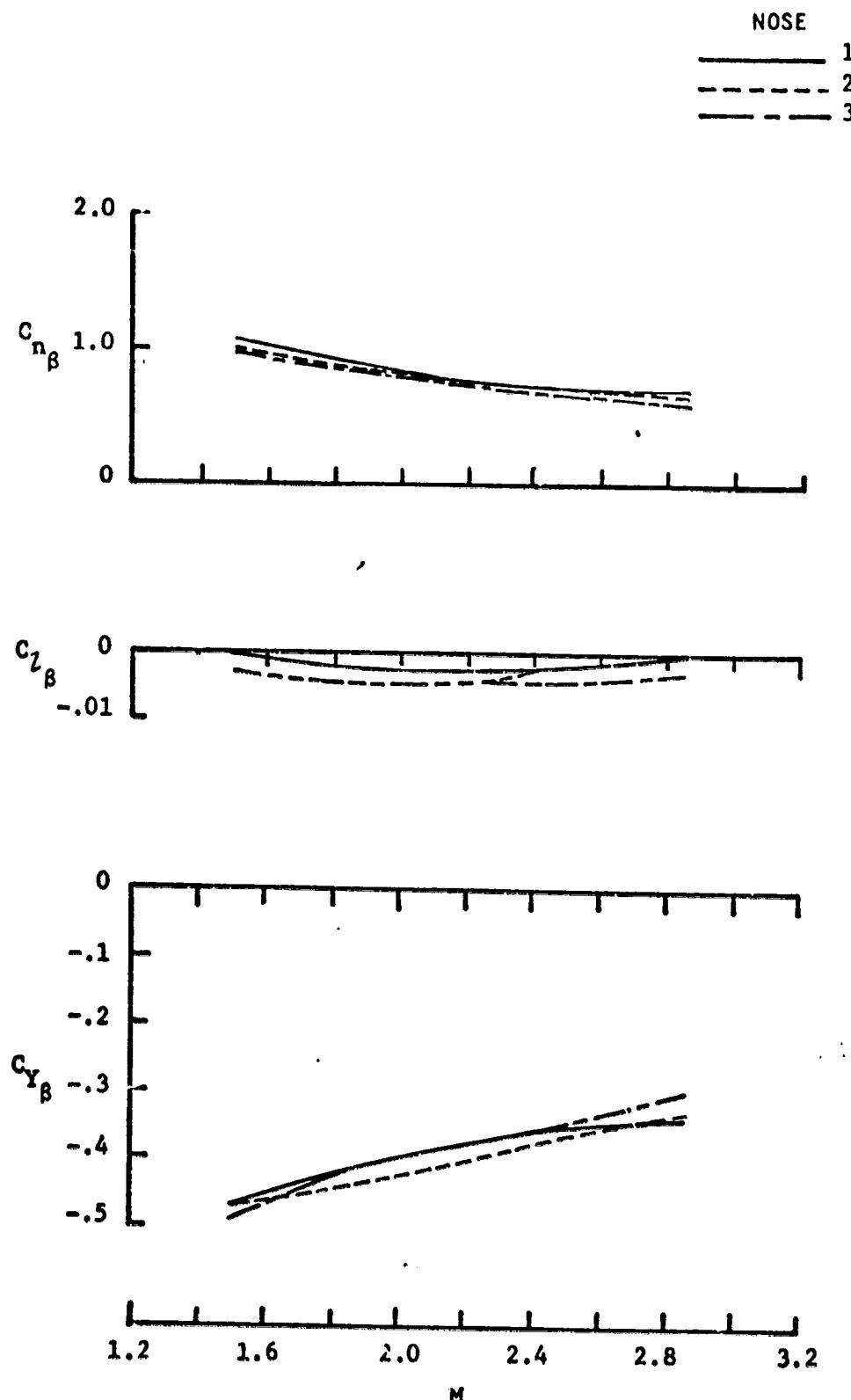


Variation of sideslip derivatives with Mach number, $\alpha=0^\circ$, $\phi=45^\circ$, mid-sized wings.



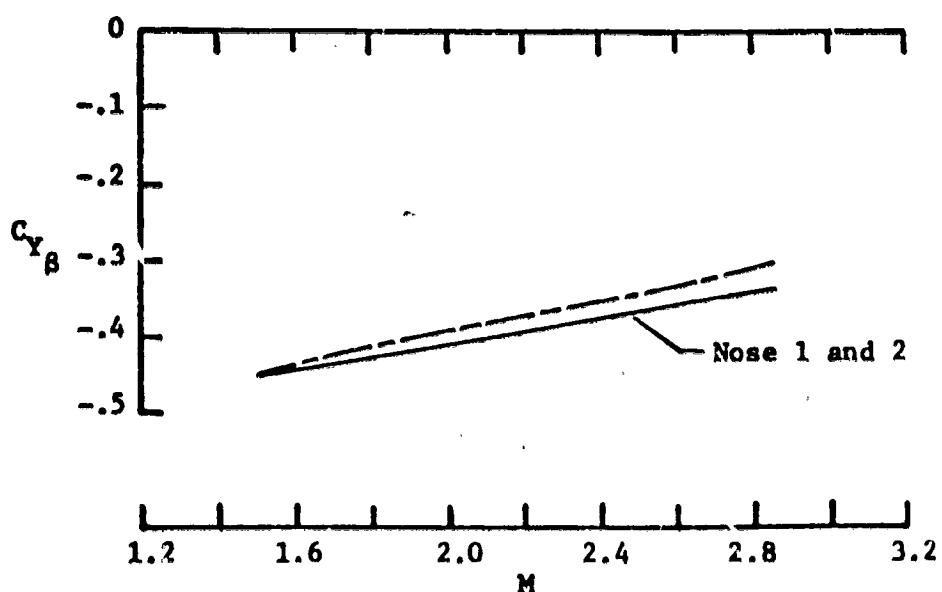
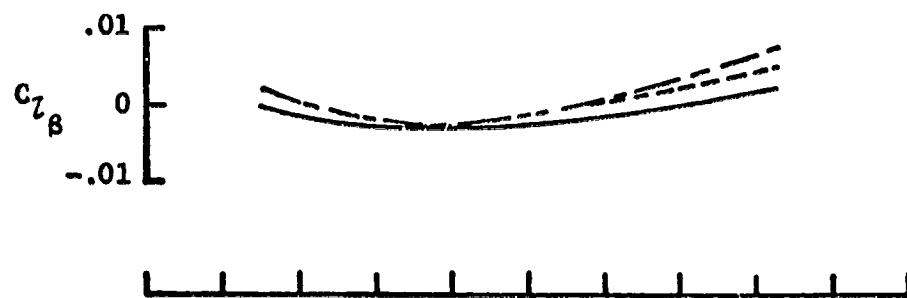
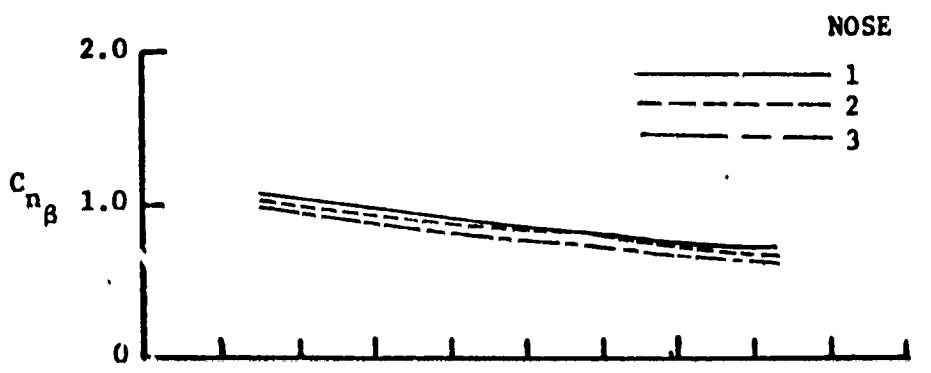
Variation of sideslip derivatives with Mach number, $\alpha=0^\circ$, $\phi=0^\circ$, mid-sized wings.

Ref. TM X-1839



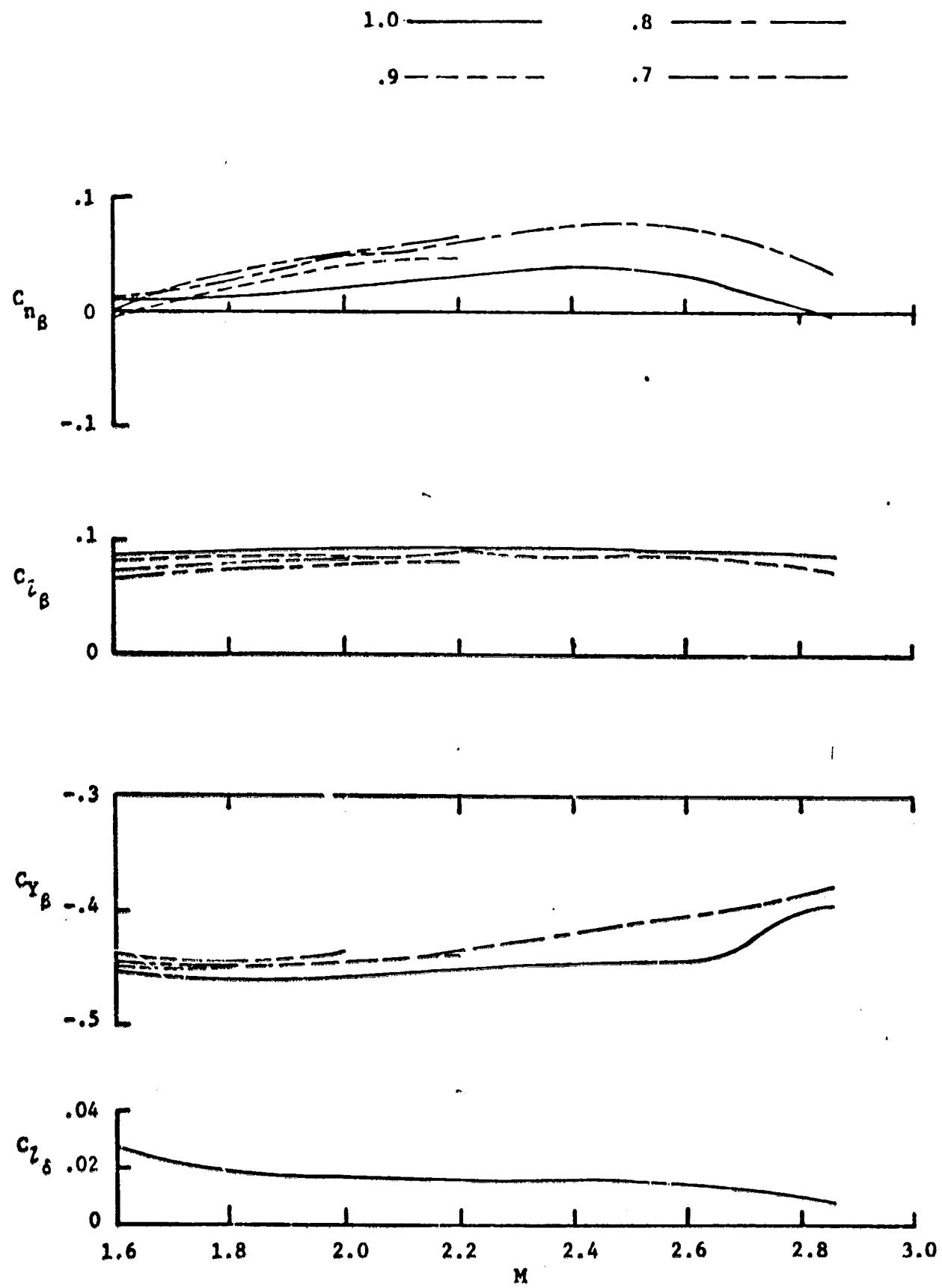
Variation of sideslip derivatives with Mach number;
 $\alpha=0^\circ$, $\phi=0^\circ$.

Ref. TM X-2289



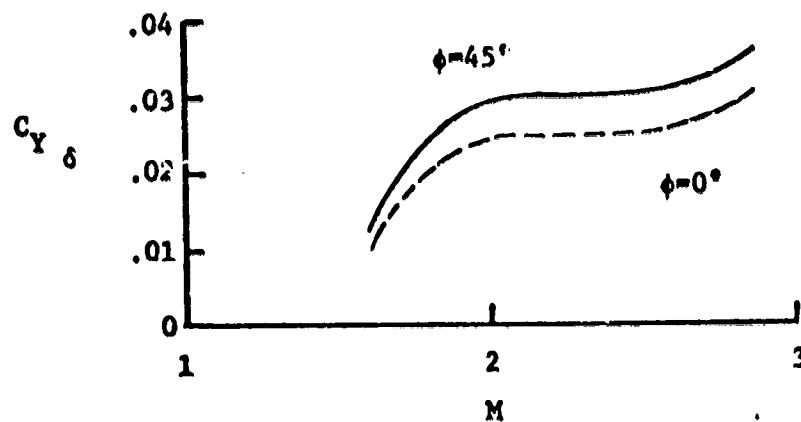
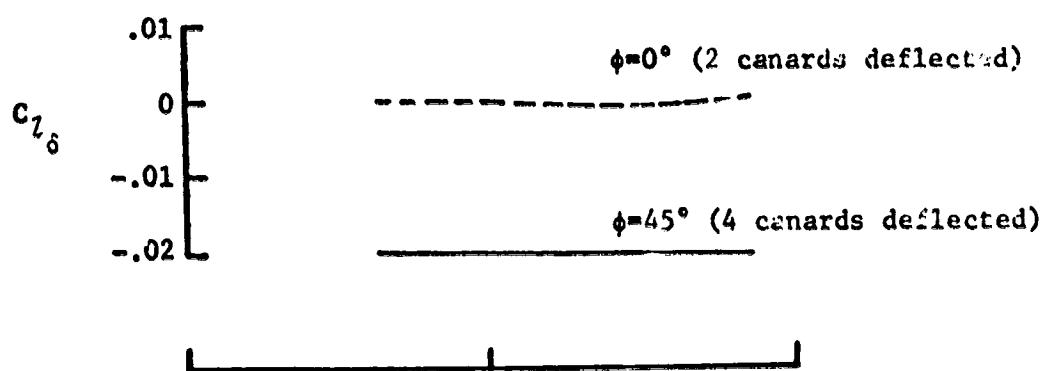
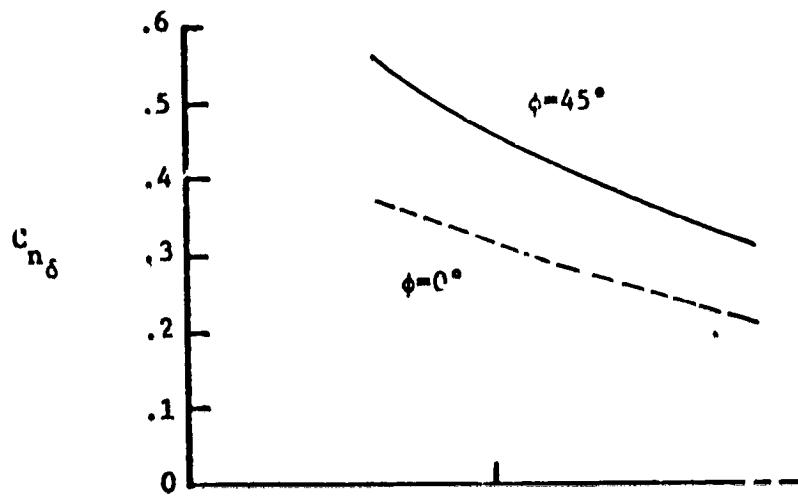
Variation of sideslip derivatives with Mach number:
 $\alpha=0^\circ$, $\phi=45^\circ$.

Ref. TM X-2289



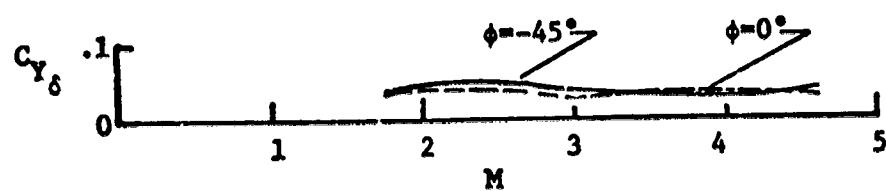
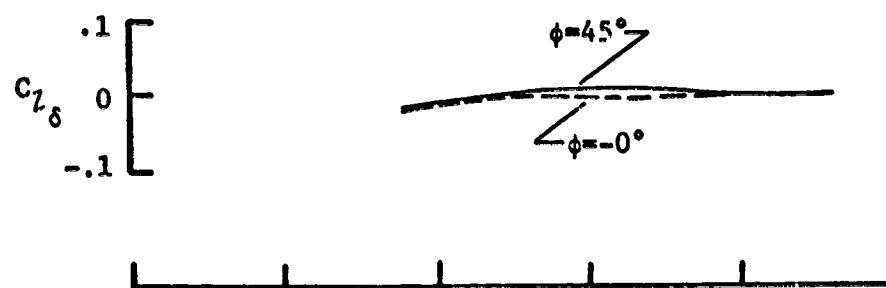
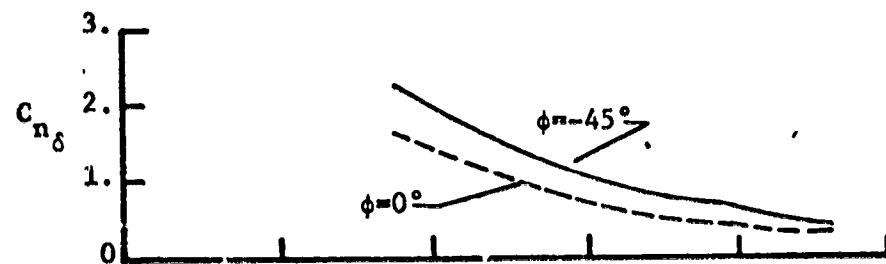
Variation of sideslip derivatives with Mach numbers; $\alpha=0^\circ$.

Ref. TM SX-2299



Directional and lateral control effectiveness of canard configuration with blunted ogive nose; $\alpha \approx 0^\circ$.

Ref. TM X-2780

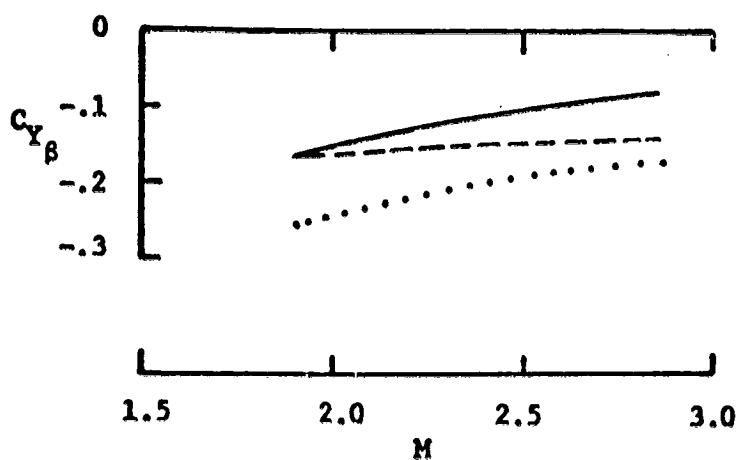
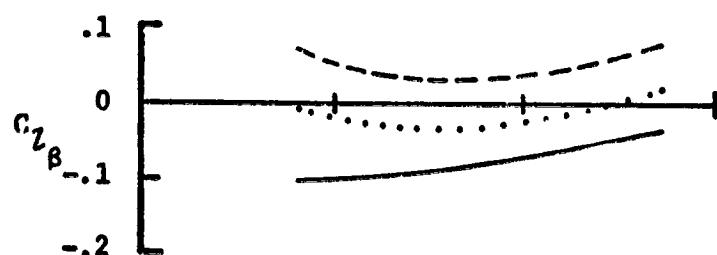
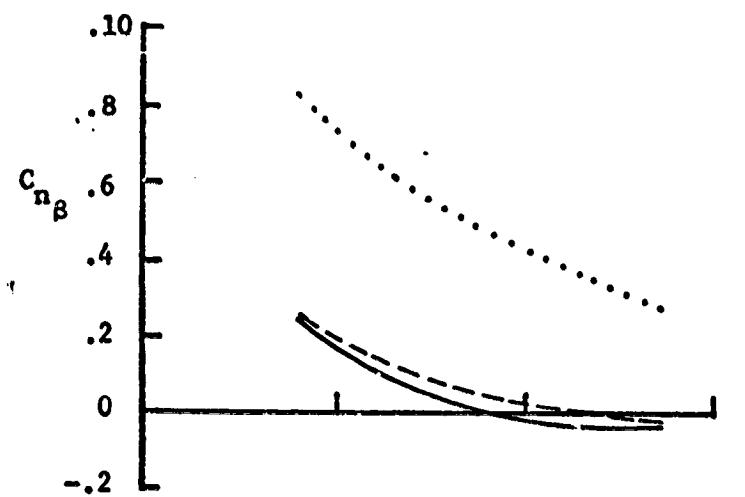


Directional and lateral control effectiveness; $\alpha \approx 0^\circ$.

Ref. TM X-3070

TAIL CONFIGURATIONS

..... X Cruciform
 - - - T Inverted
 — Conventional

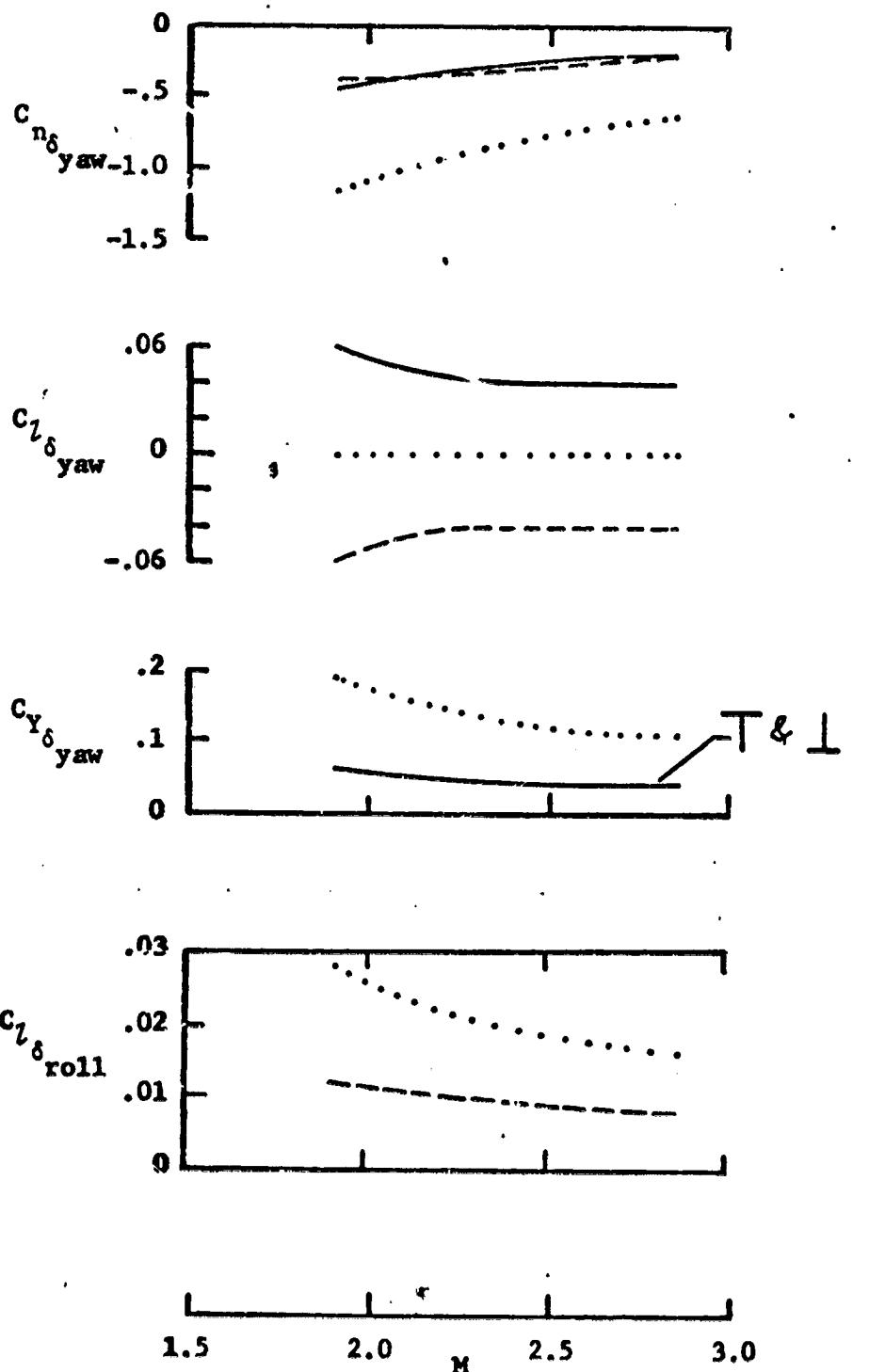


Variation of sideslip derivatives with Mach number; $\alpha = 0^\circ$.

Ref. TM X-71984

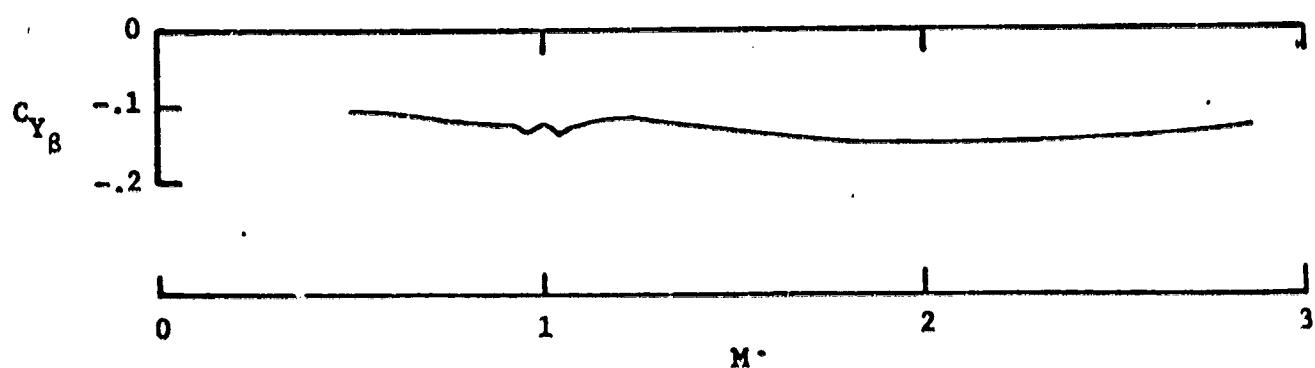
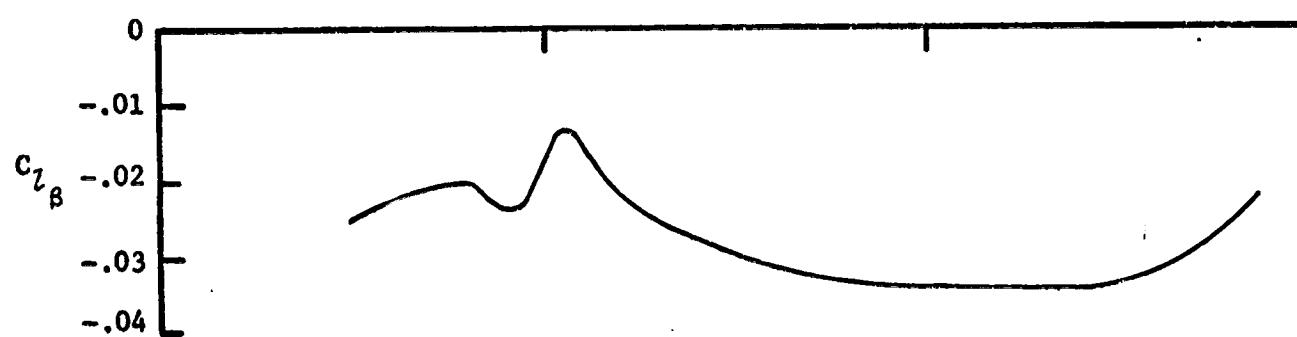
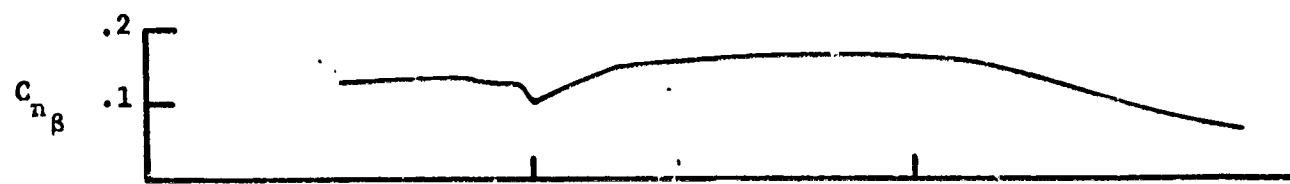
TAIL CONFIGURATIONS

..... X Cruciform
 - - - T Inverted
 — L Conventional



Directional and lateral control effectiveness; $\alpha=0^\circ$.

Ref. TM X-71984



Variation of sideslip derivatives with Mach number; $\alpha \approx 0^\circ$.

Ref. TN D-7069